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AN INVESTIGATION OF THE DIVERSION OF NORTHERN MANITOBA WATERS INTO LAKE MANITOBA

by

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A

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I. INTRODUCTION

I. 1. General

The University of Manitoba is presently undertaking a broadly based, interdisciplinary study of Water Resources and Water Utilization in Western Canada. The Department of Energy, Mines and Resources, Government of Canada has provided part of the funds for the research and investigation required for the study. It is intended that this study will result in the submission by the University of a report on future water development in Western Canada. The major objectives of the study are an assessment of the possible future scope of water development in Western Canada and the feasibility of water export to the United States.

This interdisciplinary study involves the Faculties of Engineering, Agriculture and Law and Departments of Economics, Commerce, Geography, Political Science, Sociology, Geology and Biology. Each of the disciplines involved, through research and investigation, will provide information which will contribute towards realization of the objectives of the study. Specifically, there is presently an abundance of water flowing through northern Manitoba which discharges into Hudson Bay, whereas the need for water in the United States and in the southern regions of the Prairie Provinces is steadily increasing. This gives rise to the technical problem of diverting the water from the North to the area in which it is needed. It is thus intended that the Engineering studies will reveal the diversion potential of the rivers investigated, the future requirements for water use in Western Canada and through the preliminary design of the proposed diversion works, an assessment of the feasibility of proposed diversions. The objective of the Agricultural studies will be to determine the ultimate water demand for irrigating the Canadian Prairies. The objectives of the Political Science and Law studies will be to assess jurisdictional interests in water planning in order to establish standards for analysis of future developments in this field. Similarly, each discipline will contribute special knowledge to the overall study.

This thesis has been written as part of the research and investigation performed under the direction of the Department of Civil Engineering within the scope of the interdisciplinary study of Water Resources and Water Utilization in Western Canada. The object of this thesis is to contribute to the store of basic knowledge on several diversion schemes, principally the Churchill River diversion via the Sturgeon-Weir River and the diversion of the Saskatchewan River into Lake Manitoba, by the accumulation and correlation of available information and through utilization of this information to arrive at logical and meaningful results and conclusions.

I. 2. Scope of Study

As summarized in the title, this thesis concerns an investigation of the diversion of water from several sources into Lake Manitoba. The main features of the investigation are the diversion of the Churchill River into the Saskatchewan River via the Sturgeon-Weir River, the diversion, by pumping of water from Lake Winnipeg into Cedar Lake, the headpond of the Grand Rapids reservoir, and the diversion of these flows, combined with the Saskatchewan River discharge, into Lake Manitoba via Lake Winnipegosis.

The proposed diversions represent different engineering design requirements and require separate analyses to assess the economic feasibility of each scheme. For instance, the Churchill River diversion requires the construction of relatively short sections of concrete dams, less than 60 feet in height, a relatively short length of earth fill dyking less than 40 feet in height and two sections of spillway to divert an average flow of approximately 22,000 c.f.s. by gravity into the Saskatchewan River. The diversion from Lake Winnipeg would require the installation of large pumps capable of discharging 38,000 c.f.s. against a head of approximately 125 feet. To produce the design average discharge of 29,000 c.f.s. would cost approximately 9.0 million dollars annually for pumping and would decrease the production of hydroelectric power at Grand Rapids with a potential annual value of approximately 5.5 million dollars. Finally, the diversion to Lake Manitoba would require excavation of two large diversion channels and a control structure at the outlet of Lake Winnipegosis.

In addition to the capital cost and operating cost of all the proposed schemes, an estimate must be made of the value of the energy foregone by development of these diversion schemes. Since the water which would be diverted would otherwise flow either naturally, or by the proposed Burntwood diversion through approximately 600 feet of developed head on the Nelson River, its value for this purpose must be assessed against the cost of the diversion schemes.

Lake Manitoba has been selected as the terminus of all these diversions because it is a potential distribution reservoir for various proposed schemes for the diversion of water to agricultural areas in Manitoba and Saskatchewan or to water deficient areas of the mid-western United States. This latter scheme is under investigation at the University of Manitoba by P. N. Feschuk in a thesis entitled "Lake Manitoba - Garrison Reservoir Diversion." Since this proposed diversion requires raising the water by pumping up the Assiniboine River and over the height of land into North Dakota, it is of great advantage to have the supply reservoir at the highest possible elevation. Therefore, Lake Manitoba is preferable to Lake Winnipeg because it is approximately 100 feet in elevation higher at virtually the same latitude in southern Manitoba.

I. 3. Programme of Study

This thesis is divided into three main areas of study. The first comprises the compilation of available discharge records in each drainage basin under investigation for the purpose of determining the flow available for diversion from these drainage basins at key locations. Without storage, the dependable flow available for diversion would be the minimum recorded discharge in the river. Since this is normally only a small fraction of the average discharge in the river (approximately one eighth on the Saskatchewan River, for example) it is of great advantage to develop storage reservoirs to increase the dependable flow available for diversion. Therefore, by combination of of the available discharge records with the storage capacities of the various potential reservoirs throughout the river systems investigated, the firm discharge available from the combined diversion schemes has been established.

The second part of the study involves an engineering design and cost estimate for each of the diversion schemes investigated--the Churchill River diversion, the pumping diversion from Lake Winnipeg and the combined diversion into Lake Manitoba. Estimates of cost for the required engineering works such as dams, spillway structures, canals and pumping works were made in order that the cost of these diversion schemes and their related benefits may be compared with alternative schemes for utilization of this water.

The third aspect of this study involves a discussion of other proposed water resource developments, such as the diversion, by pumping, from Lake Athabasca and diversion of the South Seal River into the Churchill River, which may affect the schemes presented in this thesis, and a proposal for scheduling these schemes so as to best co-ordinate them with existing and proposed water utilization schemes in this area.

I. 4. Limitations of Study

The validity of the results and conclusions derived from this study is partly dependent on the accuracy of the basic data on which the various aspects of the study are founded. Thus, it follows that the reliability of the cost estimates is dependent in many cases upon the accuracy of the assumed geotechnical conditions at the sites of construction for the various engineering works. The assumptions made were considered to be realistic, commensurate with the available information and indications relating to site conditions. If the assumptions appear to be optimistic, it is because the information available leads logically to the conclusion of favorable engineering conditions. For instance, at the site of the downstream control structure for the Churchill River Diversion, the observed existence of bedrock outcrop on both banks, and the high velocities and shallow depth of the channel led to the assumption that the channel bottom was bedrock. This may not be the case, however, test holes would have to be drilled to evaluate the assumption. It has also been recognized that since the assumed soils and geological conditions have such a large bearing on the over-all cost of construction, there is a definite requirement for a substantial contingency factor. If the soils and geological conditions prove to be worse than those assumed, construction of the proposed engineering works would be more difficult, and consequently, more costly. However, it is felt that construction would not be infeasible, since there are no other valuable entities which would be affected by design changes.

The cost estimates presented in this thesis are only a first estimate of the order of cost of the proposed schemes. A firm estimate of cost would require a more complete study which would include obtaining further topographical and geotechnical information, but the time and cost required to produce these results is certainly beyond the scope of this thesis. Nonetheless, this study was carried out in the belief that the engineering design and estimates of cost presented in this thesis are sufficiently reliable to influence a decision as to whether or not these proposed water diversion schemes should be included in the future planning of the water resources of Western Canada.

I. 5. Sources of Information

The information required for the preparation of this thesis falls into three main categories--

Hydrological records
Topographical detail
Geotechnical description

The hydrological records which comprise basic data for the report include the following:

TABLE I. 1.

Hydrological Records Used In Thesis

Location	Data Recorded	Period of Record	Source of Information
Churchill River at Island Falls	Discharge	1929 - 1964	Department of Energy, Mines and Resources, Water Resources Branch.
Reindeer River at outlet of Reindeer Lake	Discharge	1929 - 1964	"
Reindeer Lake at Brochet	Water Levels	1930 - 1964	"
Saskatchewan River at the Pas	Discharge	1913 - 1964	"

In general, topographical detail for this study was obtained from the 1:250,000 scale topographic map series published by the Department of Mines and Technical Surveys. However, some valuable supplementary detail on the Sturgeon-Weir River system in the form of 1 inch=4000 foot scale topographic mapping from aerial photography was obtained courtesy of Manitoba Hydro. This mapping, which included 25 foot interval contour lines, was used as the base map for Plates 3-2 and 3-4.

Topographical detail on the area between Cedar Lake and Lake Winnipegosis and Lake Winnipegosis and Lake Manitoba was obtained from the Water Control Branch, Department of Agriculture and Conservation, Province of Manitoba. This consisted of topographic mapping to various scales giving 5 foot interval contour lines at the proposed construction sites, as shown on Plates 4-2 and 4-3.

Geotechnical information was obtained in limited detail from various reports and publications on this area, referred to in the bibliography. Some further information on the Sturgeon-Weir River was obtained from observations made during a reconnaissance trip to the site of the diversion structures at Frog Portage and Reindeer River in September of 1966. However, no drilling or testing was carried out. Photographic coverage of this trip is presented in Section II of the appendix of this thesis.

I. 6. Summary

Although the complexity of the engineering works required for each of the diversions investigated in this thesis varied greatly, all the schemes were found to be feasible.

The requirements of the pumping diversion at Grand Rapids would present a more difficult challenge than the design of structures for the Sturgeon-Weir Diversion. Also, the pumping diversion would be a more expensive source of water due to the inherent operational cost of the energy requirements of the scheme. However, the decision to develop each scheme would be influenced by the demand for water and the value which is placed on water by this demand.

The water budget indicated that the proposed system of diversion schemes would produce a constant dependable inflow to Lake Manitoba of 72,000 c.f.s., from the three sources of diversion, the Churchill River at Frog Portage, the Saskatchewan River at Cedar Lake and Lake Winnipeg at Grand Rapids. Plates 1.2 and 1.3 give a comparison of present long term average inflows and outflows of major lakes in Manitoba with proposed average inflows and outflows as produced by these schemes. Plate 1.4 shows a water surface profile of the combined diversion routes.

II. WATER AVAILABLE FOR DIVERSION

II. 1. General

The water available for diversion to Lake Manitoba is derived principally from three main drainage basins, the Churchill River basin, the Saskatchewan River basin and the Lake Winnipeg drainage basin.

Although the respective drainage basins of the three sources of diversion are adjacent to one another they are dissimilar enough in physiography to have discharge patterns which do not closely correspond to one another. The Churchill basin for instance, begins in the cretaceous sediments of Alberta, north of Edmonton and flows through the Precambrian Shield of Saskatchewan to the point of diversion at Frog Portage. The main river stream consisting of a succession of lakes, has a great deal of natural storage and thus a fairly well regulated natural flow. The Saskatchewan River, bordered on the north by the Churchill basin and on the South by the Missouri basin along the international border in Alberta and Western Saskatchewan, rises in the foothills of the Rocky Mountains and flows north easterly across the prairies to the Grand Rapids reservoir, at the outlet to Lake Winnipeg. The Winnipeg River and other eastern tributaries of Lake Winnipeg drain the Precambrian Shield region of Western Ontario and Eastern Manitoba from just south of the International Border to the northern end of the lake. The dissimilar discharge patterns of these river systems mean that a combination of flows from the two rivers partially dampens out the natural extremes without requiring a great volume of storage capacity.

That is, the historical period of minimum flows in the Saskatchewan River did not coincide with minimum flows in the Churchill River or minimum inflows to Lake Winnipeg from the eastern tributaries.

II. 2. Proposed Storage

Without storage, the dependable flow of each diversion is considered to be the minimum recorded river discharge. For the Churchill River at the proposed diversion site, the minimum flow was 9500 c.f.s. For the Saskatchewan River at Cedar Lake, the minimum flow was 2700 c.f.s. By the addition of regulated storage to the diversion schemes it has been found possible to increase the dependable flow to 18,000 c.f.s. on the Churchill River diversion and 16,000 c.f.s. on the Saskatchewan River. The addition of regulated pumping inflow from Lake Winnipeg represents essentially a firm dependable discharge of 38,000 c.f.s.

The storage available for the diversions in this development scheme is made up from various potential and presently existing reservoirs in the respective river systems.

It is proposed to utilize 13 feet of regulated storage which represents 21 million acre feet on Reindeer Lake as the regulation for the Churchill River diversion via the Sturgeon-Weir River. At present, by means of the Whitesand Dam, ten feet of live storage on this lake is utilized for regulation of flows to the hydroelectric power station at Island Falls. Control of discharge on the proposed diversion would be effected by the dam and spillway at Frog Portage, thus eliminating the function of the Whitesand Dam.

At present, 12 feet of live storage on Cedar Lake is operated for the regulation of flows to the hydroelectric power station at Grand Rapids, between elevations 830 and 842. It is proposed to operate 5.5 feet of live storage on Cedar Lake, between elevations 829.5 and 835, which represents a storage volume of 1.9 million acre-feet.

It is also proposed to operate 5.5 feet of storage on Lake Winnipegosis between elevations 829.5 and 835 which represents a storage capacity of 7.2 million acre-feet. A control structure in the proposed diversion channel between Lake Winnipegosis and Lake Manitoba would regulate the storage capacity on both Lake Winnipegosis and Cedar Lake. This control structure would regulate concurrently the levels of the two lakes which would be connected by a channel to be excavated through Mossey Portage.

It is also proposed to place a level control on Lake Winnipeg to provide five feet of live storage between elevations 709 and 714 which represents a storage capacity of 30 million acre-feet.

II. 3. Assumptions Regarding Operation of Diversion Scheme

In performing the reservoir operation study, assumptions were made to establish the discharge capacities of the control works and the pattern of regulation of storage.

With regard to the Churchill River Diversion via the Sturgeon-Weir River, the natural extreme flows at the point of diversion ranged from a minimum of 9500 c.f.s. to a maximum of 57,300 c.f.s. compared with the average flow of 23,250 c.f.s.

The limits which were used for the reservoir operation study were a maximum discharge of 25,000 c.f.s. and a minimum discharge of 18,000 c.f.s. The upper limit provided a high degree of utilization of Churchill River flows without providing an excessive discharge capacity to accommodate rarely occurring high peak flows. This maximum also places a limitation on the flooded area along the diversion route. The minimum diversion discharge of 18,000 c.f.s. was obtained by operation of the reservoir in accordance with a rule curve, designed to make optimum use of the available storage capacity while allowing minimum spillage. It was assumed that a minimum discharge of 300 c.f.s. continuous would be supplied to downstream interests on the Churchill River.

It was assumed that the maximum discharge on the Saskatchewan River would be limited to 100,000 c.f.s., a discharge at which they dykes in the reclammation area would not be endangered. In cases where the diversion of the Churchill River into the Saskatchewan River would result in a discharge greater than this maximum, it was assumed that the Churchill River flows would be decreased or withheld completely as required. For the purpose of the study, it was assumed that the full discharge of the Saskatchewan River would be available to Manitoba. It is likely that only 10,000 to 15,000 c.f.s. of the long term average of approximately 22,000 c.f.s. will be available to Manitoba in the future due to consumptive uses of the water in Saskatchewan and Alberta. This would reduce the long term average flow available for diversion and would also reduce the storage capacity required within the diversion scheme.

A further assumption was made that the Cedar Lake--Lake Winnipegosis reservoir would be operated so as to minimize the pumping head from Lake Winnipeg. Thus, Cedar Lake would be drawn down to elevation 833.8 before any pumping commenced. Similarly, the outlet control on Lake Winnipeg would maintain a higher average tail-water than under normal circumstances to reduce the pumping head. Storage hydrographs are shown on Plate 2.1.

II. 4. Water Budget

The water budget for the combined scheme of diversions was derived by combination of the available discharge records (1929 to present) with the storage capacities at the various locations outlined in section II. 2., operated so as to produce the maximum firm diversion discharge into Lake Manitoba. This complete operation is given in section I. of the appendix of this thesis.

II. 5. Available Diversion Capacities

The diversion of the Churchill River at Frog Portage would produce an average of 21,820 c.f.s. out of the long term average of 23,210 c.f.s. at this point. The diversion of the Saskatchewan River at Cedar Lake would produce 21,220 c.f.s. out of the long term average of 21,350 c.f.s. at that point. Finally, the pumping diversion from Lake Winnipeg at Grand Rapids would produce an average of 28,960 c.f.s. The discharges from both the Churchill and Saskatchewan Rivers represent in excess of 90% utilization of flows.

II. 6. Quality of Diverted Water

The intention of this proposed development is to provide water for multipurpose use such as for irrigation, industrial consumption and domestic consumption. Thus, it is important to make an assessment of the quality of the water available from the various sources.

Concern has been expressed over the fact that the diverted flows from Northern Manitoba water courses will be passed through Lake Manitoba which contains rather poor quality water. Reference to the report by J. F. J. Thomas entitled "Industrial Water Resources of Canada--Water Survey Report No. 10" verifies the poor quality of the water sampled from Lake Manitoba. In comparing it with common standards for water quality, it is apparent that the Lake Manitoba water does not meet domestic consumption requirements. It has a high dissolved sodium content which makes it substandard for most irrigation purposes and it is rather poor for most industrial needs due to such characteristics as high total solids content, high total hardness, colour and turbidity.

However, various sources familiar with problems of water supply and treatment have expressed the common opinion that the chemical characteristics of the water samples largely reflect the conditions of the source of the water supply. In the case of Lake Manitoba, which draws water from a low relief poorly drained area, ground water mainly from granular sedimentary deposits is the source of supply.

It is stated in "Ground Water Hydrology" by D. K. Todd, "All ground waters contain salts carried in solution. Ordinarily, higher proportions of dissolved constituents are found in ground waters than in surface waters because of the greater exposure to soluble materials in geologic strata--Poorly drained areas, particularly basins having interior drainage, contain high salt concentrations. Sedimentary rocks are more soluble than igneous rocks--Sodium and calcium are commonly added cations; bicarbonate, carbonate and sulphate are corresponding anions." It appears that the chemical characteristics of the water in Lake Manitoba are indicative of the ground water supplied to the lake. It can, therefore, be presumed that the quality of the water which discharges from Lake Manitoba under the proposed system of diversions will reflect a combination of the chemical characteristics of all the sources of supply. Since the long term average inflow to Lake Manitoba is in the order of 3000 c.f.s., these inflows will have only a small effect on the quality of the outflow compared to that of the 70,000 c.f.s. diverted from other river systems. However, assuming a diversion outflow from Lake Manitoba of 72,000 c.f.s., it would require 2 to 3 months to flush out the volume of undesirable water currently stored in the lake.

An analysis of the water sources from the Churchill River, Saskatchewan River and Lake Winnipeg, given in the "Industrial Water Resources of Canada" indicates that the water from all these sources is well within the suggested water quality tolerances given by D. K. Todd for both industrial and agricultural uses and with varying degrees of treatment it would be economically feasible to improve these supplies to domestic consumption standards.

III. DIVERSION OF THE CHURCHILL RIVER INTO THE SASKATCHEWAN RIVER VIA THE STURGEON-WEIR RIVER.

III. 1. General

The diversion of flows from the Churchill River to other river basins is not a new or unusual proposal. Investigations of various possible diversions to increase hydroelectric power production in adjacent river basins have been carried out by various interests during the past fifty years. Currently, the initial phase of the development of hydroelectric power on the Nelson River by the Manitoba Hydro and the Federal Government includes the diversion of the Churchill River via the Burntwood River into the Nelson River.

As early as 1917, in a report by Rust, 1920 in a report by Flanagan, and in 1922 in a report by Patterson, it was proposed to divert water from the Churchill River into the Sturgeon-Weir River for the purpose of producing hydroelectric power on the latter. In all the early investigations, however, the diversion flow under consideration was less than 5000 c.f.s.

Diversion of the Churchill River via the Sturgeon-Weir River at Frog Portage is not an unusual suggestion for another very important reason. Because of the topography of the river basin in that vicinity, a natural diversion of the Churchill River into the Sturgeon-Weir River takes place at Frog Portage at times of high discharge on the Churchill River. The flood swollen river overflows its banks and spills into Wood Lake, the northern end of the Sturgeon-Weir drainage basin. Professor E. Kuiper observed this phenomenon in a canoe trip to this area in September, 1954 and from his interviews with the natives at Pelican Narrows, it may be concluded that this overflow condition has occurred five times since 1880.

The location of the point of diversion is at Frog Portage, approximately twenty miles upstream of the confluence of the Reindeer River with the Churchill River. It is, however, most benificial to construct a control dam downstream of this confluence in order to utilize discharge from the Reindeer River, which is approximately equal to the Churchill River discharge at that point, and take advantage of the vast storage capacity on Reindeer Lake, for regulation of the diversion flows. The diversion site is approximately 80 miles northwest of Flin Flon, Manitoba, the nearest centre served by rail and highway connections.

The maximum headwater level, elevation 1106, which would provide the storage capacities and dependable flow, as outlined in Chapter 2, would increase the level of the entire Reindeer River and the Churchill River between Keg Lake and the downstream control structure to elevation 1106.

III. 2. Topography and Geology

The general topography of the diversion route under investigation can be separated into two natural divisions, corresponding to the underlying geological units. The Churchill River channel and the upper reaches of the Sturgeon-Weir River, as far downstream as Maligne Lake are in the Pre-Cambrian region and the lower reaches of the Sturgeon-Weir River flow through a flat area which is underlain by bedrock of the Paleozoic group.

The major portion of the diversion route is situated in the Pre-Cambrian region. Many steep rock faces are visible along the banks of the Churchill River in the section immediately upstream and downstream of the proposed diversion site and rock formations are generally in the form of knolls and ridges.

The banks of the Churchill River upstream of Frog Portage range from one hundred to several hundred feet in height, rising steeply from the water's edge, in general. However, at Frog Portage, the high ridge on the south bank drops rapidly to a low ridge covered with willow and poplar growth, which continues at less than 25 feet above the water surface elevation for approximately one mile in length and then the bank rises rapidly again to a height of approximately 200 feet above the river level.

From an aerial reconnaissance of the area by the writer, in September, 1966, the Frog Portage site was observed to be overlain by an undetermined depth of overburden. However, the existence of bedrock outcrops at the site and less than a thousand feet upstream and downstream of the proposed spillway suggests the overburden may be fairly shallow. The report on a survey of Frog Portage in 1917 by H. P. Rust presents rock contours which indicate the depth of overburden to be less than 10 feet at the spillway site.

From an inspection on foot of the site of the downstream control structure in September, 1966, rock outcrop on both abutments was observed. Tree cover is predominantly spruce and poplar. From the water surface, where the channel width is approximately 200 feet, the rocky banks rise steeply to a level of approximately elevation 1200 approximately 100 feet above the proposed headwater level at elevation 1106. Depth sounding taken in this narrow channel showed a fairly shallow depth of 13 to 15 feet. This shallow depth and the existence of rock on both abutments indicated the probable existence of rock in the channel bottom.

The northern reach of the Sturgeon-Weir River consists of a series of lakes, Wood, Manawan, Pelican, Mirond and Corneille, all of which have high banks (up to 200 feet above the water surface.) Tree cover is predominantly spruce, poplar and birch.

Downstream of Corneille Lake, the channel has high, rocky banks and as the river emerges from the Pre-Cambrian region to the Paleozoic region, the banks become lower, with more marshy stretches in evidence. Amisk Lake is characterized by a limestone shoreline ranging in height from 5 feet to 30 feet.

Downstream of Amisk Lake the relief is very low with the general ground level being less than 50 feet above the river channel. The channel drops rapidly a total of approximately 100 feet in the 25 miles between Amisk Lake and Namew Lake.

Low level aerial photographs of the diversion route taken in September, 1966, provide a more graphic indication of the topography of the area. A selection of some of the more pertinent ones is given in the appendix of this thesis.

III. 3. Climate

The Atlas of Canada, 1957, classifies the Churchill

River basin as a sub-arctic climatic region. The Sturgeon-Weir River has it headwaters in this sub-arctic region but flows primarily through a climatic region classified as "Humid Continental, Cool Summer, no dry season." The temperature range in this general area of the diversion is -60 to +100 degrees Farenheit. The total annual precipitation is approximately 16 inches and there are approximately one hundred frost-free days. This along with the fact that the diversion site is in an area of discontinuous permafrost may possibly demand a shorter than normal yearly construction period and some specialized construction techniques.

III. 4. General Arrangement of Structures

The general arrangement of structures for the proposed Churchill River diversion shown on Plates 3.2 and 3.4 assumes a headwater level of elevation 1106. The arrangement consists of a gate-controlled overflow spillway with a capacity of 155,000 c.f.s. and concrete gravity dams to a maximum height of 65 feet, founded on bedrock downstream of the confluence of the Churchill River with the Reindeer River plus a gate-controlled sluiceway at Frog Portage for the release of regulated diversion flows as high as 25,000 c.f.s. and short sections of earth fill dykes with a maximum height of 40 feet.

Plate 3.3 shows the downstream control structure consisting of a concrete gravity dam and gate-controlled overflow spillway located in a narrow section of channel on the Churchill River, 1200 yards downstream of the confluence with the Reindeer River. The gate-controlled spillway is intended to provide an outlet for extreme flood flows as well as maintaining a specified minimum discharge from the reservoir to serve downstream interests on the river. The entire structure would be constructed within cofferdams while a tunnel constructed in the south bank of the river would convey the natural river flows during the construction period. Road access to the site would be from the southwest, with a parking area on the south bank.

The Frog Portage control structure shown on Plate 3.4 consists of a gate-controlled sluiceway flanked by two short sections of concrete gravity dam and approximately 5000 feet of earth fill dyke to the south of the sluiceway which would complete the reservoir enclosure to a level of elevation 1112. Because of the elevation of the site above normal water levels, the entire structure would be constructed in the dry. Road access would be from the east, with parking area on the east side of the structure.

III. 5. Dams

The downstream control structure would be connected to the abutments by two sections of concrete gravity dam, each approximately 200 feet in length with a maximum height of 65 feet and founded on bedrock.

Two other short sections of concrete gravity dam totalling about 150 feet in length would separate the sluiceway at Frog Portage from the earth fill dykes on the left and right abutments. Earth fill dykes adjacent to the concrete gravity dams would be of homogeneous material.

Two other lengths of earth fill dyke, totalling about 5000 feet in length, are required to complete the reservoir enclosure. These dykes to the south of the sluiceway at Frog Portage would have mainly homogeneous sections with transitions to zoned earth fill embankments for dykes greater than 25 feet in height to a maximum of 40 feet in height. Since it is likely that areas of permafrost will be encountered, an allowance has been made for sand drains and foundation treatment in these areas. From the available topographical mapping, it appears that no saddle dyking will be required beyond the limits shown on Plates 3.2 and 3.4.

A cross section through a typical gravity dam section is shown on Plate 3.3. Cross sections through typical earth fill sections are shown on Plate 3.5.

III. 6. Spillway and Sluiceway

The general arrangement for the Churchill River diversion via the Sturgeon-Weir River comprises a sluiceway at Frog Portage and spillway immediately downstream of the confluence of the Reindeer River with the Churchill River.

The spillway which is located approximately 1200 yards downstream of the confluence of the two above-mentioned rivers serves a two fold purpose. The first function of the spillway would be to pass extreme flood discharges which might occur in the Churchill River basin, while the second function would be to pass a constant riparian flow to the channel downstream of the control dam. The design discharge for the spillway was selected by means of a frequency plot of annual peak flows at

Island Falls for the period of recrod 1929 to the present. From this flood frequency analysis a discharge of 155,000 c.f.s., which corresponds to a frequency of 1 in 10,000 years was selected as the spillway design capacity. The value of property damaged or the number of lives endangered by a possible dam failure is small. However the cost of providing this spillway capacity rather than that corresponding to 1 in 1000 years is not great. Therefore, the spillway was designed for a flood frequency of 1 in 10,000 years. At the maximum headwater level of elevation 1106, five 38 by 44 feet fixed-wheel vertical lift gates placed at a sill elevation of 1065 would provide the required spillway capacity. The gates would be operated by fixed hoists placed in a gallery supported above the deck by steel towers founded on the piers. A monorail with hoist jib would be used to install the upstream stop logs which would be provided for maintenance of the gates. The downstream side of the gates would be dewatered with the gates closed because of the elevation of the sill above tailwater at the site. A cross-section through this spillway is shown on Plate 3.3.

The sluiceway or control structure, at Frog Portage would regulate the diversion flows to the Sturgeon-Weir River. Four 31 feet by 37 feet fixed-wheel vertical lift gates placed at a sill elevation at 1072 would be capable of passing the maximum diversion flow of 25,000 c.f.s. at a headwater level at elevation 1089, or the minimum diversion flow of 18,000 c.f.s. with a headwater level at elevation 1086. As in the downstream spillway the gates would be operated by fixed hoists placed in a gallery supported above the deck by steel towers founded on the piers. Upstream stop logs, serviced by a hoist job and monorail, would be provided for maintenance of the gates. A cross section through this sluiceway is shown on Plate 3.5.

III. 7. Flooding Along Diversion Route

The maximum headwater level of elevation 1106 would cause some flooding on the Churchill River upstream of Frog Portage as far as the western end of Keg Lake. The entire Reindeer River and the Churchill River downstream as far as the control structure would also be raised to elevation 1106. The flooding in these areas would be confined mainly to the river channels since they are contained by banks which rise steeply more than one hundred feet above the present water surface. No habitations, other than a few seasonal hunting and fishing shacks would be affected by these increased levels.

Backwater computations which were performed in this study indicate that the maximum diversion flow conditions would raise the water levels along the Sturgeon-Weir River channel less than 10 feet. This would result in only slight effects on the two settlements along the diversion route, Pelican Narrows and Sturgeon Landing. These effects would present no insurmountable problems, the main requirements being possible relocation of few shoreline structures and relocation of all docks, landings and bridges. The flooding along the diversion route may be decreased by excavation of rapids and control sections at key locations to reduce the level of the backwater upstream of these sections. Gated control dams would be installed to maintain water levels under low flow conditions. These works have not been designed in detail, but a lump sum of 2.5 million dollars has been included in the cost estimate for them.

Topographic surveys will be required to provide the information for a more precise computation of backwater curves in order to make an accurate forecast of future water levels. The approximate extent of flooded areas is shown on the location map for the proposed diversion shown on Plate 3.1.

An allowance has been made in the cost estimates for costs incurred in flooding areas along the diversion. The cost of any proposed channel improvement for the purpose of lowering the water levels along the diversion route would have to be compared with the cost of flooding in order to decide on the extent of channel improvement which is required.

III. 8. Construction Diversion and Scheduling

Because of its elevation above the normal water levels on the Churchill River, the sluiceway, concrete gravity dams and earth fill dykes at Frog Portage would be constructed without any need for cofferdamming or diversion of flows. The construction of these works would take place prior to construction of the downstream spillway section in order to provide an outlet capacity for a portion of the excess flows of a possible flood on the Churchill River during the construction diversion period. This scheduling would allow a reduction in the size of the diversion tunnel and, hence, a reduction in the large cost of the diversion works. The construction time for the Frog Portage control structure would be approximately two years.

The downstream control structure would be constructed entirely within cofferdams with a diversion tunnel in the south bank of the Churchill River which would bypass the maximum diversion flow of 40,000 c.f.s.

By means of the Whitesand Dam and spillway at the outlet of Reindeer Lake, this storage reservoir could be drawn down prior to construction on the downstream control structure. Reindeer Lake could then be utilized as a detention basin during the construction period in order to reduce the outflow to the Reindeer River and, thus, reduce the required capacity of the diversion tunnel. It would appear that the potential saving in cost would warrant including this measure in the construction schedule.

The construction time on the second phase of the diversion would be approximately two and a half years. However, part of the construction such as the tunneling could be carried on concurrently with construction at Frog Portage, making the total construction time approximately four years.

III. 9. Estimate of Cost

An estimate of capital cost shown on the following pages has been prepared for the development outlined. The cost estimate does not include the cost of acquisition of flooded lands.

The cost of all other items associated with the work, including interest during construction, engineering and inspection, exploration, administration, access and transportation, and construction camps have been included.

The total estimated cost for the development is $18,000,000.

CHURCHILL RIVER DIVERSION

SUMMARY

ESTIMATE OF CAPITAL COST

DIRECT ITEMS	
A. DOWNSTREAM CONTROL STRUCTURE	
1. Diversion and Dewatering	$1,610,000
2. Spillway and Concrete Gravity Dam	4,030,000
B. FROG PORTAGE CONTROL STRUCTURE	
3. Spillway and Concrete Gravity Dam	950,000
4. Earth Fill Dykes	790,000
5. Channel Improvement	2,500,000
Total Direct Items	$9,880,000
Contingencies	1,120,000
Total Direct Capital Cost	$11,000,000
INDIRECT ITEMS	
6. Access and Transportation	$2,790,000
7. Construction Camp	250,000
8. Cost of Flooding	1,000,000
Sub-Total (6,7,8)	4,040,000
Contingencies	190,000
Sub-Total	$4,230,000
9. Engineering and Supervision	660,000
10. Surveys and Investigations	500,000
11. Administration and Insurance	440,000
Sub-Total (Items 6 to 11)	$5,830,000
12. Interest During Construction	1,170,000
TOTAL INDIRECT CAPITAL COST	$7,000,000
TOTAL DIRECT CAPITAL COST	11,000,000
TOTAL CAPITAL COST	$18,000,000

CHURCHILL RIVER DIVERSION

DETAILED COST ESTIMATE

D I R E C T   I T E M S

Item	Quantity	Unit	Rate	Amount
A. DOWNSTREAM CONTROL STRUCTURE				
1. Diversion and Dewatering				
Upstream cofferdam				
rockfill	24,000	c.y.	$ 2.50	$ 60,000
impervious fill	5,800	c.y.	1.75	10,150
removal		l.s.		14,900
Downstream cofferdam				
rockfill	13,000	c.y.	2.50	32,500
impervious fill	4,560	c.y.	1.75	7,980
removal		l.s.		8,780
Dewatering and Seepage Control		l.s.		150,000
Tunnel				
rock excavation	21,000	c.y.	50.00	1,050,000
liner	2,600	c.y.	50.00	130,000
closure		l.s.		150,000
	Total			$1,614,310
			Say	$1,610,000
2. Spillway and Concrete Gravity Dam				
Clearing and grubbing	5	acres	500.00	2,500
Earth excavation	5,000	c.y.	1.50	7,500
Rock excavation	14,250	c.y.	4.50	64,125
Foundation preparation	5,950	s.y.	5.00	29,750
Pressure grouting		l.s.		59,500
Concrete				
in piers and side walls	9,210	c.y.	41.00	377,610
in deck	390	c.y.	110.00	42,900
in rollway and apron	21,724	c.y.	28.00	608,272
in gravity bulkhead	10,662	c.y.	28.00	298,536

Item	Quantity	Unit	Rate	Amount
2. Spillway and Concrete Gravity Dam (Cont'd)				
Waterproofing joints		l.s.		$ 15,000
Miscellaneous steel		l.s.		20,000
Gates and hoists	5	ea.	93,000.00	465,000
Stoplogs		l.s.		46,500
Gate heaters		l.s.		27,500
Cement	185,738	bags	1.70	315,755
Reinforcing steel	829,260	lbs.	.18	149,267
Foundation contingency				1,500,000
	Total			$4,029,715
			Say	$4,030,000

B. FROG PORTAGE CONTROL STRUCTURE

Item	Quantity	Unit	Rate	Amount
3. Spillway and Concrete Gravity Dam				
Earth excavation	5,700	c.y.	1.25	7,125
Rock excavation	2,100	c.y.	4.50	9,450
Foundation preparation	1,900	s.y.	5.00	9,500
Pressure grouting		l.s.		19,000
Concrete				
in piers	2,800	c.y.	41.00	114,800
in deck	266	c.y.	110.00	29,260
in rollway and apron	5,071	c.y.	28.00	141,988
in gravity bulkheads	5,960	c.y.	28.00	166,880
Waterproofing joints		l.s.		12,000
Miscellaneous steel		l.s.		10,000
Gates and hoists	4	ea.	55,800.00	223,200
Stoplogs		l.s.		17,250
Gate heaters	4	ea.	5,500.00	22,000
Cement	61,649	bags	1.70	104,803
Reinforcing steel	321,390	lbs.	.18	57,850
	Total			$950,356
			Say	$950,000
4. Earth Fill Dykes				
Clearing and grubbing	15	acres	350.00	5,250
Stripping	45,000	c.y.	1.25	56,250
Earth fill	263,570	c.y.	2.50	658,925
Rip rap and slope protection	15,000	c.y.	3.00	45,000
Sand drains		l.s.		25,000
	Total			$790,425
			Say	$790,000

Item	Quantity	Unit	Rate	Amount
5. Channel Improvement			l.s.	$ 2,500,000
Total Direct Items				9,880,000
Contingencies				1,120,000
Total Direct Capital Cost				$11,000,000
6. Access and Transportation				
Access roads	72	mi.	$35,000.00	$2,520,000
Maintenance		l.s.		150,000
Parking areas		l.s.		120,000
Total				$2,790,000
7. Construction Camp				
Buildings, services and operation		l.s.		$ 25,000
8. Cost of Flooding				
Relocation of structures affected by flooding		l.s.		$1,000,000
Sub-Total (6,7,8)				4,040,000
Contingencies				290,000
Sub-Total				$4,330,000
9. Engineering and Supervision		l.s.		$600,000
10. Surveys and Investigations		l.s.		$500,000
11. Administration and Insurance		l.s.		$400,000
12. Interest During Construction				
4,000,000 @ 5.5% for 36 months				$572,894
4,890,000 @ 5.5% for 18 months				480,921
6,900,000 @ 5.5% for 6 months				187,190
Total Interest During Construction				$1,169,005
Say				$1,170,000
TOTAL INDIRECT CAPITAL COST				$7,000,000
TOTAL DIRECT CAPITAL COST				11,000,000
TOTAL CAPITAL COST				$18,000,000

III. 10. Potential Power Development on the Sturgeon-Weir River

The proposed diversion of the Churchill River via the Sturgeon-Weir River to the Saskatchewan River would descend some 230 feet along the Sturgeon-Weir River. A portion of this could be developed at various sites for the production of electrical energy. Some of these sites have already been investigated in studies by Rust, Flanagan and Patterson, which were mentioned previously. These studies, which considered only the natural flows of the river and the possible addition of up to 4500 c.f.s. concluded that several sites could be developed economically for the production of hydroelectric power. However, due to their remoteness from markets and the existence of sites with greater energy potential, the Sturgeon-Weir River was not developed as a source of hydroelectric power. The greatly increased flows resulting from the diversion of the Churchill River would now make development of potential power sites an attractive consideration.

A brief examination of the topography of the diversion route indicates three good potential sites. Approximately 30 feet of head could be developed at the site of the control structure at Frog Portage. At a site referred to as Birch Rapids, located 2 miles upstream of Maligne Lake, it appears economically feasible to develop approximately 45 feet of head. This would, however, greatly raise water levels upstream at the settlement of Pelican Narrows. It appears economically attractive to develop approximately 35 feet of head at Spruce Rapids, located five miles upstream of Amisk Lake. Although no estimates of cost have been made for development of these sites, there are no apparent costly deterrents to their development. The remaining 100 feet of head downstream of Amisk Lake appears uneconomical to develop because of the flat relief of the surrounding area and the lack of a good potential site along this stretch of the river.

The power which would be obtained from development of sites along the Sturgeon-Weir River could replace the power loss due to the proposed diversion of approximately 50 feet of developed head at the Island Falls Generating Station on the Churchill River.

III. 11. Effects of the Diversion on Other Interests

It is apparent that the diversion of the Churchill River via the Sturgeon-Weir River into the Saskatchewan River would affect other resources and activities in the area. The effects on resources such as mining, fishing, wildlife and forestry as well as human activity and enterprise is of great interest and importance in the overall assessment of the scheme. The interdisciplinary study can take advantage of the special experience of representatives from various disciplines to make a detailed assessment of the effects. However, from an examination of the extent of flooding and the areas in which it occurs, several observations can be made.

The 3 foot increase in maximum storage level on Reindeer Lake would likely have little effect on the small amount of commercial fishing which is carried on in this lake. Since little or no fishing of any value is carried on in the

Reindeer River or Churchill River between Frog Portage and the confluence with the Reindeer, the effects would not be harmful economically. The increased levels on Wood, Manawan, Pelican and Mirond Lakes would likely affect fishing on these lakes to a certain extent. The inhabitants of Pelican Narrows might require recompensation for food losses until the biological cycle would adjust to the new conditions. Downstream of this area, the effects of the diversion on fishing would be small.

The effects of the diversion on wildlife in the area are likely to be insignificant, since flooded areas are very small in comparison to present water areas and are well distributed throughout the diversion route. The natural habitat of water margin dwelling creatures might be altered slightly, but no reduction of species should result.

Since there are undoubtedly potential commercial timber stands in the area, the diversion provides large flows for a potential timber logging route to the proposed pulp and paper development at The Pas. The slight increase in water levels affects only narrow strips of timber along shorelines, little of which has any potential commercial value.

Since the flooded areas are generally narrow belts along the present water's edge, the effect of the diversion on potential mining development in the area would not be adverse.

The access roads which would be required to the proposed construction sites would be an asset to other forms of development in the area. Transportation facilities would encourage more mining exploration as well as potential logging operations.

The diversion would not require the relocation of any communities in the area. It is anticipated that some buildings and waterside structures at Pelican Narrows and Sturgeon Landing would require relocation, however, the major part of these settlements would be unaffected. Construction activity would provide short term employment for the inhabitants, while increased activity in the area might lead to long term employment in industrial operations.

IV. DIVERSION FROM CEDAR LAKE TO LAKE MANITOBA

IV. 1. General

The diversion of flows from Cedar Lake to Lake Manitoba involves construction at two locations. Firstly, a channel would be excavated through the narrow neck of land which separates Cedar Lake from Lake Winnipegosis and secondly a channel would be excavated between Lake Winnipegosis and Lake Manitoba. This latter channel would be integrated with a gate controlled spillway to regulate storage on Cedar Lake and Lake Winnipegosis and earth fill dykes to control flooding at the southern end of Lake Winnipegosis, and block off the Waterhen River, a natural water course which presently drains Lake Winnipegosis into Lake Manitoba.

The spillway at the Grand Rapids Hydroelectric development with a capacity of 83,000 c.f.s. at a headwater level of elevation 835 and the assumed constant diversion flow of 72,000 c.f.s. to Lake Manitoba would provide a spillage capacity of 155,000 c.f.s. for release of flood flows on the Saskatchewan River, which is greater than the present capacity of the Grand Rapids spillway. The control structure on the Fairford River provides an outlet capacity of 10,000 c.f.s. while the proposed turbine pumps at Grand Rapids are capable of passing 50,000 c.f.s. It has been assumed that the diversions to the south would require a constant flow of 72,000 c.f.s. The reservoir at Cedar Lake - Lake Winnipegosis was made a common one with maximum level at elevation 835 to provide a smaller head for the proposed Grand Rapids pumping installation.

If, however, it must be assumed that the diversion flow to the south might be cut off at any time, there would not be sufficient flood spillage capacity in the system, in which case a control structure would be required in the channel between Cedar Lake and Lake Winnipegosis. This control structure would permit raising of the water level on Cedar Lake to elevation 845 in order pass a design flood of 140,000 c.f.s. at the Grand Rapids spillway.

The diversion channel between Cedar Lake and Lake Winnipegosis would be located at Mossey Portage a relatively low-relief narrowing of the isthmus which separates the two lakes. Mossey Portage is approximately 11 miles west of Easterville and some 36 miles west of the hydroelectric development at Grand Rapids. The present ground elevations across the route of the proposed diversion channel rise from a shoreline elevation of approximately 842 on Cedar Lake to a high point of elevation 870 and then decline more sharply to a shoreline elevation of 832 on Lake Winnipegosis. The location of the proposed diversion channel is shown on Plate 4.1.

The diversion channel to be constructed between Lake Winnipegosis and Lake Manitoba would be a less costly alternative to improvement of the 25 miles of natural channel of the Waterhen River. This natural channel has a present capacity of less than 10,000 c.f.s. as compared to the proposed diversion flow of 72,000 c.f.s. The new channel would be located at Meadow Portage, at the south east end of Lake Winnipegosis. The channel would be excavated through the narrowest point of the land separating the two lakes and would run parallel and adjacent to an existing section road approximately 3 miles south of the present Meadow Portage Post Office and some 12 miles east of the town of Winnipegosis. Present ground elevations across the route of the proposed diversion channel rise from a shoreline elevation of approximately 832 on Lake Winnipegosis to a maximum elevation of 838 and than decline to a shoreline elevation of approximately 812 on Lake Manitoba.

Access to the Meadow Portage site is presently available, however, approximately 12 miles of road would have to be constructed for access to the Mossey Portage site.

In order to produce a constant outflow of 72,000 c.f.s. from combination of the diverted Churchill River flows, natural Saskatchewan River flows and pumping inflows from Lake Winnipeg, 9.1 million acre-feet of storage would be required in this scheme. Since present agricultural and other development around Lake Manitoba would tolerate a very small range of levels on the lake (the Water Control Board have proposed regulation between elevation 811 and 813), this storage requirement was made up on Cedar Lake and Lake Winnipegosis. Thus, the control structure at Meadow Portage would regulate an inflow of 72,000 c.f.s. to Lake Manitoba, which would be equal to the outflow for diversion to the south and west. By maintaining the same storage range on Cedar Lake and Lake Winnipegosis, the requirement for a control structure in the Mossey Portage channel is eliminated. Also, the maximum reservoir level at elevation 835 would reduce the pumping head by 7 feet from the present maximum storage level at elevation 842.

The maximum water level of elevation 835 on the Cedar Lake-Lake Winnipegosis reservoir would adversely affect various towns and settlements on the lake shores. An assessment of this is made later in the chapter for the purpose of obtaining an estimate of cost for this proposed diversion.

IV. 2. Geology and Topography

The isthmus of land separating Cedar Lake from Lake Winnipegosis consists primarily of a glacial till deposit. Test drilling conducted by the Water Control Branch, Department of Agriculture and Conservation, Province of Manitoba, in 1950 indicated the deposit to contain primarily clay with some sand and boulders interspersed. Test holes were drilled to a minimum depth at elevation 800 in all cases without contacting bedrock. The only test hole which was drilled to bedrock located it at elevation 739.6. The bedrock underlying this area is classified as Paleozoic era, Silurian age Dolomitic limestone with minor argillaceous beds.

The ground relief has a maximum elevation of approximately elevation 870. Ground cover consists of moss with sparse tree cover.

The Meadow Portage diversion site is also covered by a glacial till. Test holes drilled in 1950 indicated primarily white clay with some gravel and boulders. Test holes were drilled to depths varying from elevation 804 to elevation 823 without encountering bedrock. Bedrock underlying this area would be of the same classification as at Mossey Portage.

Ground cover consists of hayland, marsh and wooded areas. Maximum ground level is approximately elevation 840.

IV. 3. Climate

The Atlas of Canada, 1957, describes the area in which the diversion channels are proposed as "humid continental, cool summer, no dry season". The temperature extremes range from -55 to +100 degrees. The total annual precipitation is approximately 18 inches and there are approximately one hundred frost free days. Some permafrost was encountered during drilling operations at Mossey Portage in 1950. This is, however, more common under a cover of moss, and it may be expected that removal of the moss ground cover would hasten thawing of permafrost pockets.

IV. 4. General Arrangement

The proposed general arrangement for diversion of flows from Cedar Lake to Lake Manitoba consists of two elements. Plate 4.2 shows the diversion channel between Cedar Lake and Lake Winnipegosis, while Plate 4.3 shows the diversion channel between Lake Winnipegosis and Lake Manitoba.

The proposed channel between Cedar Lake and Lake Winnipegosis, at Mossey Portage, would be excavated almost entirely in the dry, apart from short sections at each end, which would require dredging. The arrangement shown on Plate 4.2 assumes a maximum reservoir level of elevation 835 on the two lakes which would be connected.

The proposed general arrangement at Meadow Portage shown on Plate 4.3 assumes a maximum headwater level of elevation

835 and construction primarily in the dry. Excavation of the diversion channel at both ends would be completed by means of dredging.

The general arrangement consists of the diversion channel, approximately 35 miles of homogeneous earth fill dykes most of which are less than 10 feet in height and a gate-controlled spillway, located approximately 1000 feet from the downstream end of the diversion channel. The earth fill dykes extend north eastward beyond the Waterhen River in order to cut off the present natural outlet of Lake Winnipegosis and approximately 5 miles south of the channel. Dykes adjacent to the channel would complete the reservoir enclosure to the elevation 842.

Road access to the Meadow Portage construction site exists in the form of section roads between Toutes Aides and Meadow Portage P.O. This road would also form the line of the primary dyking in this area. Approximately 12 miles of road would be constructed from Easterville for access to the Mossey Portage site.

IV. 5. Diversion Channels

The diversion channel at Mossey Portage would be approximately 20,000 feet in length. The channel has a bottom width of 1400 feet, side slopes of 2:1 and a minimum depth of flow of 14.5 feet. The invert at the upstream end has been set at elevation 815, while the downstream invert is at elevation 813.8. The channel cross-section has been designed to pass the normal design discharge of 72,000 c.f.s. at velocities less than 3 f.p.s. The head loss under these conditions would be 1.2 feet. Under temporary conditions, the channel would pass extreme flood flows at maximum velocities of 3.5 f.p.s. In order to avoid erosion of the channel bed material the channel velocities have been maintained within the limits set out by Fortier and Scobey, 1926. A cross-section through the trapezoidal channel is shown on Plate 4.4, while the plan view is shown on Plate 4.2.

The diversion channel at Meadow Portage, which is trapezoidal in cross-section would be approximately 10,000 feet in length. The channel has a bottom width of 1600 feet, side slopes of 2.5:1 and a minimum depth of flow of 14.5 feet. The control structure and earth fill dykes which border the diversion channel have a top elevation at 842, which allows 7 feet of freeboard above maximum water level. The upstream invert is at elevation 815, while the sill elevation at the control structure is at elevation 812. A local deepening of the channel upstream of the spillway would maintain velocities less than 3 feet per second. The channel downstream of the spillway would have an invert elevation of 792. A cross-section through the channel is given on Plate 4.4, while the plan view is shown on Plate 4.3.

To allow for some overload to compensate for temporary reducations in flow due to control structure maintenance or mis-operation of storage, the control structure and channels have been checked for a discharge of 80,000 c.f.s. The structure and channels are capable of passing this discharge, which is equivalent to 10% greater than normal, within the allowable velocities.

IV. 6. Earth Fill Dykes

Approximately 35 miles of homogeneous earth fill dykes would be required to complete the reservoir enclosure at the southeastern end of Lake Winnipegosis. This dyking is made up of approximately 7000 feet adjacent to each bank of the diversion channel between the spillway and the upstream end of the channel, approximately 5 miles of dyke to the southwest of the channel at less than 10 feet in height, and approximately 26 miles of dyke to the northeast of the channel. The latter section of dyke, most of which is less than 10 feet in height, crosses and contains the Waterhen River, the present natural outlet of Lake Winnipegosis. The maximum earth fill section is approximately 25 feet in height and the average is 10 feet. The cross section has a top width of 20 feet with side slopes of 2:1 and 3:1. Sections through the earth fill dykes are shown on Plate 4.4. Available topographic mapping with 25 foot contour intervals was used to determine the limits of the required dykes.

IV. 7. Control Structure

The control structure at Meadow Portage would be located in the centre of the diversion channel, approximately 1000 feet from the downstream end. Nine 26 ft. by 40.5 ft. fixed-wheel vertical lift gates placed at a sill elevation of 812 would provide the required spillway capacity of 72,000 c.f.s. at a minimum headwater level of elevation 829.0. The gates would be operated by fixed hoists supported above deck level by structural steel towers. Upstream stoplogs would be provided for maintenance of the gates. The spillway would be flanked on each side by two sections of reinforced concrete breastwall which connect the spillway with an earth fill section. A bridge deck would be constructed for access across the spillway. The spillway chute would be constructed on original ground with well compacted consolidated gravel for drainage and concrete cutoffs would be provided at the upstream and downstream ends of the spillway.

IV. 8. Development Schedule

The total construction time for this diversion project would be approximately 3 years. Construction would be carried out simultaneously at the two sites in order to have completion of the two portions coincide fairly closely.

IV. 9. Effects of Raised Water Levels

Although the proposed reservoir storage range on Lake Winnipegosis is within the range of historical extremes on the lake, there would undoubtedly be a more common occurrence of higher levels than is presently experienced. According to information obtained from the Lakes Winnipeg and Manitoba Board Report, the extreme range of levels on Lake Winnipegosis during the historical period of record was elevation 826.6 to elevation 835.6. It is proposed to regulate 5.5 feet of storage between elevations 829.5 and 835.0 on Lake Winnipegosis. Whereas the level of Lake Winnipegosis exceeded elevation 833.5 three times during the 44 year period of record, this level would likely have been exceeded at least once a year in all but three years under the proposed storage regulation conditions. However under the assumed reservoir operation conditions, elevation 834 would have been exceeded only approximately once in 3 years. A comparison of the present Stage-Duration Curve with one corresponding to the proposed diversion scheme is shown on Plate 4.5.

From investigation into available topographic and geodetic information, it is apparent that flood damage occurs in various developed areas along the lake at a water level of elevation 835. Moreover, the maximum storage level of elevation 835 could likely be increased temporarily in the order of two feet due to wind setup conditions. Thus, it is necessary to appraise the possible extent of damage due to flooding by high water levels.

An examination of a topographic plan of the town of Winnipegosis, showing one foot contour intervals, indicates that a portion of the town adjacent to the Mossy River would be inundated at a lake level of elevation 835, which was verified by the experiences of 1954 and 1955. Most of the remainder of the town, however, would be unaffected. Most recent buildings and appurtenances, such as the hospital and the sewage lagoon, (dyke elevation 840.5) have been designed to cope with high water levels. The town of Camperville and settlements at Duck Bay and Shoal River, all located on the lakeshore are affected to some extent by high lake levels. The post office at Meadow Portage could be located in the lee of the proposed dyking at the southeast end of the lake.

In view of the damage which can be anticipated from the proposed high water level on Lake Winnipegosis some permanent dyking near developed areas might be warranted. Thus, an amount of $1,000,000 has been allowed in the cost estimate for relocation of structures and construction of permanent dyking. Should this amount be greatly exceeded, it need not be greater than approximately $2,000,000, which would be the cost of constructing a control structure in the channel at Mossey Portage. If flooding costs prove to be excessive, an alternative would be to develop the required storage capacity by regulating eight feet of storage on Cedar Lake, between elevations 834 and 842, and three feet of storage on Lake Winnipegosis between elevations 830 and 833, with the addition of a gate-controlled spillway at Mossey Portage.

IV. 10. Estimate of Cost

An estimate of capital cost has been prepared for the development outlined assuming a constant diversion of 72,000 c.f.s. The cost estimate, presented on the pages that follow, includes the cost of all items associated with the work such as interest during construction, engineering and inspection, administration, construction camps and exploration. No recompensation for the loss of potential power production was included since this will be referred to elsewhere in this thesis.

The unit price which has the greatest influence on the cost of this scheme is that of earth excavation. According to information received from the Water Control and Conservation Board, Province of Manitoba, the price range for earth excavation on the Red River Floodway was 18.9¢ to 41¢ per cubic yard. The average price for reasonably good clay material such as found in the Mossey Portage and Meadow Portage area was 27¢ per cubic yard. However, it is believed that the remoteness of the site and the limited working season would necessitate a considerably higher unit price. Therefore, 40¢ per cubic yard was used.

Information supplied by Atomic Energy of Canada Limited indicates that at present cost levels, the Mossey Portage channel could be excavated by large scale Nuclear blasting (2 M.T. charges) for approximately one third of the cost of conventional means. However, the cost of the present and long term effects of radiation on biological life in the area, as well as the potential effects of shock waves on nearby structures are too complex to assess at present. Nevertheless, technical advancement may make this method more attractive in the foreseeable future.

The total estimated cost of construction is $48,000,000.

DIVERSION FROM CEDAR LAKE TO LAKE MANITOBA

SUMMARY

ESTIMATE OF CAPITAL COST

DIRECT ITEMS

A. CHANNEL BETWEEN CEDAR LAKE AND LAKE WINNIPEGOSIS (MOSSEY PORTAGE)

1. Diversion Channel	$19,430,000

B. CHANNEL BETWEEN LAKE WINNIPEGOSIS AND LAKE MANITOBA (MEADOW PORTAGE)

2. Diversion Channel	7,650,000
3. Earth Fill Dykes	5,690,000
4. Spillway and Stilling Basin	2,280,000
Total Direct Items	$35,050,000
Contingencies	3,550,000
	$38,600,000

INDIRECT ITEMS

5. Access and Transportation	470,000
6. Construction Camps	400,000
7. Cost of Flooding	1,000,000
Sub-Total (5,6,7)	$1,870,000
Contingencies	90,000
Sub-Total	$1,960,000
8. Engineering and Supervision	$2,200,000
9. Surveys and Investigations	350,000
10. Administration and Insurance	1,460,000
Sub-Total (Items 5 to 10)	$5,970,000
11. Interest During Construction	3,430,000
TOTAL INDIRECT CAPITAL COST	$9,400,000
TOTAL DIRECT CAPITAL COST	38,600,000
TOTAL CAPITAL COST	$48,000,000

DIVERSION FROM CEDAR LAKE
TO LAKE MANITOBA

DETAILED COST ESTIMATE

D I R E C T   C O S T

Item	Quantity	Unit	Rate	Amount
A. CHANNEL BETWEEN CEDAR LAKE AND LAKE WINNIPEGOSIS (MOSSEY PORTAGE)				
1. Diversion Channel				
Clearing and grubbing	688	acres	$300.00	$ 206,400
Earth Excavation				
scraper	45,842,000	c.y.	.40	18,336,800
dredge	2,181,000	c.y.	.50	1,090,500
	Total			$19,427,300
			Say	$19,430,000
B. CHANNEL BETWEEN LAKE WINNIPEGOSIS AND LAKE MANITOBA (MEADOW PORTAGE)				
2. Diversion Channel				
Clearing and grubbing	574	acres	300.00	172,200
Earth excavation	12,170,000	c.y.	.40	4,868,000
scraper				
dredge	5,567,000	c.y.	.50	2,783,500
	Total			$7,651,500
			Say	$7,650,000
3. Earth Fill Dykes				
Clearing and grubbing	596	acres	300.00	178,800
Stripping	950,000	c.y.	.70	665,000
Earth fill				
re-use	256,000	c.y.	.50	128,000
from borrow	2,061,000	c.y.	1.50	3,091,500
Rip-rap	250,000	c.y.	4.00	1,000,000
Slope Protection	250,000	c.y.	2.50	625,000
	Total			$5,688,300
			Say	$5,690,000

Item	Quantity	Unit	Rate	Amount

B. CHANNEL BETWEEN LAKE WINNIPEGOSIS AND LAKE MANITOBA (MEADOW PORTAGE) CONT'D

4. Spillway and Stilling Basin

Item	Quantity	Unit	Rate	Amount
Foundation preparation	12,690	s.y.	$ 4.00	$ 50,760
Concrete				
in piers	5,555	c.y.	41.00	227,755
in rollway slab	10,448	c.y.	28.00	292,544
in stilling basin slab	13,103	c.y.	28.00	366,884
in stilling basin walls	2,150	c.y.	30.00	64,500
in breastwall	900	c.y.	55.00	49,500
in deck	1,547	c.y.	110.00	170,170
in cutoff	896	c.y.	29.00	25,984
Rip-rap	4,630	c.y.	4.00	18,520
Backfill	9,900	c.y.	1.25	12,375
Waterproofing joints		l.s.		25,000
Gates and hoists	9	ea.	45,000.00	405,000
Gate heaters	9	ea.	5,500.00	49,500
Stoplogs		l.s.		22,500
Miscellaneous steel		l.s.		10,000
Cement	155,696	bags	1.65	256,898
Reinforcing steel	1,303,450	lb.	.18	234,621
	Total			$2,282,511
			Say	$2,280,000
	Total Direct Items			$35,050,000
	Contingencies			$ 3,550,000
	Total Direct Capital Cost (A + B)			$38,600,000

INDIRECT ITEMS

Item	Quantity	Unit	Rate	Amount
5. Access and Transportation				
Access Roads	12	mile	$35,000.00	$ 420,000
Maintenance				50,000
Total				$ 470,000
6. Construction Camp				
Buildings, services and operation		l.s.		$ 400,000
7. Cost of Flooding				
Relocation of shoreline facilities and possible permanent dyking		l.s.		$1,000,000
Sub-Total (5,6,7)				$1,870,000
Contingencies				90,000
Sub-Total				$1,960,000
8. Engineering and Supervision		l.s.		$2,200.000
9. Surveys and Investigations		l.s.		$ 350,000
10. Administration and Insurance (4% of Total Direct Capital Cost)		l.s.		$1,460,000
11. Interest During Construction				
11,300,000 @ 5.5% for 30 months				$1,618,431
17,400,000 @ 5.5% for 18 months				1,455,075
13,200,000 @ 5.5% for 16 months				358,103
Total				$3,431,609
			Say	$3,430,000
TOTAL INDIRECT CAPITAL COST				$ 9,400,000
TOTAL DIRECT CAPITAL COST				$38,600,000
TOTAL CAPITAL COST				$48,000,000

V. INSTALLATION OF PUMPING CAPACITY AT GRAND RAPIDS

V. 1. General

Approximately 40 percent or an average of 28,960 c.f.s. out of the total diverted flows to the Lake Manitoba watershed have been assumed to be available from Lake Winnipeg, by means if a pumping installation at Grand Rapids.

This average pumping discharge represents the usable water supply for diversion to Lake Manitoba, corresponding to an installed pumping capacity of 38,000 c.f.s. That is, depending on the Saskatchewan River discharge and the storage level of the Cedar Lake - Lake Winnipegosis reservoir, water from Lake Winnipeg would not be pumped at all times, as illustrated in the Reservoir Regulation Study presented in Section 1 of the Appendix. This, an installed pumping capacity of 38,000 c.f.s. would be required to pump an average of 28,960 c.f.s.

A thesis entitled "The Co-ordination of Water Export With Power Development on the Nelson River" is currently being written by Mr. E. T. Wagner, as part of the University of Manitoba Interdisciplinary Water Resources Study. An objective of this thesis would be to establish the discharge required to maintain the firm capacity of the proposed Nelson River Hydro-electric developments when placed in the peak of a future energy load curve. However, preliminary results have indicated a maximum pumping capacity in the order of 40,000 c.f.s. could be installed on Lake Winnipeg. Moreover, assuming a minimum dependable discharge requirement of 3000 c.f.s. on the Nelson River, five feet of storage would have to be regulated on Lake

Winnipeg to provide a firm pumping capacity of 38,000 c.f.s. This is considered to be the maximum desirable range of regulation on the lake.

This proposal would definitely be a more expensive source of water supply than the ones previously investigated, due to the inherent operational cost of providing the energy required to pump the water against a head of more than one hundred feet.

This pumping diversion, as well as the other diversions proposed in this thesis would reduce the flow at the proposed power developments on the Nelson River. An assessment of the value of power lost is made in Chapter VII of this thesis.

There are two obvious alternative arrangements for pumping water between the two lakes. One would be to convert the Grand Rapids Hydroelectric Generating Station to a dual purpose pumping-generating installation. This proposal would maintain the hydro-electric capacity of the station for short term operation in the peak of the system load, while also providing the capacity for pumping the required water demand for diversion to Lake Manitoba. The alternative to this arrangement would be the construction of a new pumping installation on the Dauphin River--Fairford River system which would pump directly between Lake Winnipeg and Lake Manitoba. Although this latter scheme would reduce the pumping head by 20 feet and thus reduce the operational cost of the scheme, it was rejected after a brief economic comparison of the two schemes, presented later in this chapter. The proposed water levels of the various lakes in the scheme are illustrated on Plate 1.2.

Assuming that a water diversion scheme of this nature would not be required in the immediate future, it may be possible to co-ordinate the proposed installation with the eventual replacement of the present turbine-generators at the end of their service life, some 50 to 60 years from now.

V. 2. General Arrangement

The installation of pumping capacity at Grand Rapids would require the replacement of the turbines with Deriaz or Francis pump-turbines and the replacement of the generators with reversible motor-generators. It may also be possible for the generators to be adapted to motor-generator duties. Replacement of these units would also require some adjustments to the power-hourse civil works such as scroll cases, draft tubes, intakes and thrust bearings and the addition of trashracks on the outlets. Technological advancement may simplify the adjustments when the conversion is contemplated. The operation of pumping from Lake Winnipeg would also require a control at the natural outlet of Lake Winnipeg to maintain a level of elevation 714 in order to provide sufficient pumping storage. Controlling the lake level would prevent excessive outflows from the lake during periods of low inflow. Since the pumping installation would withdraw an average of 62% of the inflow to Lake Winnipeg, storage is required to maintain the pumping capacity firm during prolonged periods of low inflow to the lake. As discussed earlier in the Chapter and in Chapter II, five feet of storage would be required (709 to 714). This control need only be an overflow weir to provide discharge capacity for maximum flood flows and a low level gate controlled outlet to provide a minimum dependable discharge of 3000 c.f.s. to downstream interests on the Nelson River. A more sophisticated control arrangement at Warren's Landing is currently under investigation by Manitoba Hydro.

The presently installed turbines at Grand Rapids have their distributor centrelines set at elevation 691.3 which is well below the minimum tailwater level at elevation 709. A pump-turbine would not likely require any lowering of the draft tube or blade setting in order to function as a self-priming pump. In an article by F. E. Jaski entitled "Pump-Turbines - 1954 Progress Report," it is stated, "Reversible pump-turbines can be built in sizes as large as are practical for Francis turbines. They can be built to develop 150,000 h.p. and more in a single machine, if a suitable motor generator can be matched to their speed and power." It would be desirable to replace the Grand Rapids units which are rated at 150,000 h.p. with reversible units of a similar size which would also provide the required discharge capacity of 38,000 c.f.s. If, however, it is not possible to design four units to provide the required pumping capacity, it would be necessary to use a greater number of smaller units.

V. 3. Estimate of Cost

An estimate of capital cost has been prepared for conversion of the Grand Rapids Hydroelectric Generating Station to a pumping-generating installation. The total capital cost of $22,000,000 includes replacement of turbine-generators with reversible machines, adjustments to civil works necessitated by the new units and construction of a control for the natural outlet of Lake Winnipeg. The loss of potential power generation at Grand Rapids amounts to approximately 5.5 million dollars annually, on the basis on a unit cost of 3 mills per kilowatt-hour.

The estimated cost for replacement of units, which is the largest item of the estimate, is considered to be conservative, but fairly accurate. Manufacturers do not supply estimates without detailed design data on the machinery. The estimate was, however, based on the most recent costs available form Manitoba Hydro.

The estimate of cost for the installation is as follows:

Replacement of turbine-generators with reversible units	$15,000,000
Adjustments to civil works at Grand Rapids development	3,000,000
Outlet control for Lake Winnipeg	1,000,000
Engineering and contingencies	3,000,000
TOTAL	$22,000,000

V. 4. Economic Comparison of Alternative Pumping Installations

As mentioned earlier in this chapter, there is an alternative to the installation of pumping capacity at Grand Rapids which would reduce the operating cost of the pumping diversion. Installation of a pumping station on the Fairford River - Dauphin River watercourse between Lake Manitoba and Lake Winnipeg would reduce the pumping head by approximately

20 feet.

Assuming the value of firm electrical energy to be 3 mills per kilowatt hour, the 20 foot reduction in pumping head would represent a saving in the operational cost of 1.5 million dollars annually. Taking the annual charges on the new pumping station to be 7.5%, an expenditure of $20,000,000 in excess of the cost of conversion of Grand Rapids would be warranted. Thus, if the capital cost of installation of a pumping station at the Fairford River were less than $42,000,000, this alternative would be preferable to the scheme at Grand Rapids. However, it is estimated that a new pumping installation of this magnitude at the Fairford River would cost in the order of $75,000,000 to $100,000,000.

V. 5. Schedule of Development

The completion of the Grand Rapids pumping scheme would require approximately two years. At the Grand Rapids site, access and accomodation for the construction period are available. Adjustments to the civil works would take approximately one year, while installation of units would take another year. The reversible pump-turbine units would have to be ordered approximately two to three years prior to installation. The construction of the outlet control works would require approximately one year and could be scheduled simultaneously with the construction at Grand Rapids.

VI. OTHER DIVERSIONS

VI. 1. General

Brief consideration has been given to two other diversion schemes - the diversion by pumping from Lake Athabasca to Wollaston Lake and thence by gravity into Reindeer Lake, and diversion of the South Seal River into the Churchill River at Southern Indian Lake. An assessment was made of the effects of these two proposed schemes on the developments investigated in this thesis. No attempt has been made to estimate the cost of these diversions, or the magnitude of the diversion works required.

VI. 2. Pumping Diversion From Lake Athabasca

a) Introduction:

A thesis entitled "A Study of the Feasibility of Water Diversion From Lake Athabasca to Lake Manitoba" is currently being written at the University of Manitoba by R. A. Madder. This thesis involves the design and cost estimates for the major works required for the pumping diversion of water from Lake Athabasca via the Fond-du-Lac River to Wollaston Lake, and thence by gravity along the route of the proposed Churchill River Diversion to Lake Manitoba. The economic and engineering feasibility of this scheme will be assessed as well as the optimum diversion capacity. Preliminary investigations indicate that an average discharge capacity of 50,000 to 60,000 c.f.s. would be available through this diversion.

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b) Assessment:

A backwater computation was performed on the Sturgeon-Weir River for a maximum discharge of 40,000 c.f.s. This backwater computation indicated that a headwater level of elevation 1086 would be required at Frog Portage in order to pass this discharge. This compares with a level of elevation 1082 required to pass the design discharge of 25,000 c.f.s. from the Churchill River diversion. Both of these levels are much below the minimum storage level of elevation 1093 on Reindeer Lake required for storage of Churchill River flows. From these calculations it is reasonable to assume that the headwater level required to pass 70,000 c.f.s. down the river channel would not be greater than elevation 1093. The spillway at Frog Portage is capable of passing 70,000 c.f.s. at a headwater level of elevation 1106. Gates would have to be added to allow the structure to pass 70,000 c.f.s. at the minimum headwater level.

c) Conclusions:

It would be feasible to pass the combined flows of the Churchill River diversion and a pumping diversion from Lake Athabasca down the Sturgeon - Weir River channel, however, more detailed investigations would be required to assess the effects of the greatly increased flows on water levels along the river and the extent of flooding. The settlements at Pelican Narrows and Sturgeon Landing might require relocation, under these conditions. The increased flows would likely be contained within the high banks of the upper reaches of the river, north of Maligne Lake, however downstream of Amisk Lake where the banks are lower the adjacent lands could be innundated in many areas. The possibility of diversion of flows from Lake Athabasca would also have effects on the Saskatchewan River. Dykes in the Saskatchewan Delta Reclammation area would have to be raised. A rough estimate of the order of cost for such a measure would be 10 million dollars, however, a more thorough study would be required to obtain an accurate cost. The possibility of upstream developments decreasing the available Saskatchewan River discharge would make available capacity for greater diversion flows.

VI. 3. South Seal River Diversion

a) Introduction

The close proximity of various lakes on the South Seal River basin to various tributaries of the Churchill River invites consideration of the South Seal as a possible source of additional flows to the Churchill River which could then be added to the Nelson River by the proposed Churchill River diversion route, via the Rat and Burntwood Rivers. At one point along the South Seal River, a divide of less than a mile separates the southern tip of Big Sand Lake from the Churchill River drainage basin. Similarly, approximately 50 miles downstream, a divide of less than a mile separates Trout Lake which discharges into Chipewayan Lake on the South Seal River from Little Sand Lake which discharges into the Churchill River at Southern Indian Lake. Therefore, an assessment was made of the probable discharge which would be available for discharge into the Churchill River.

b) Assessment

No records of discharge on the South Seal River were available, other than miscellaneous measurements taken by the Water Resources Branch. Thus, an estimate of the runoff factor of the drainage basin was made, by comparison with nearby drainage basins on which a long term period of discharge records was available. The average runoff on the Burntwood River, which is approximately 100 miles to the south of the South Seal drainage basin is 0.56 c.f.s. per square mile. The average runoff of the Reindeer River basin located approximately 150 miles to the west of the Seal River is 0.52 c.f.s. per square mile. Basins farther north show a slightly smaller runoff. For example, the Snare River, in the Northwest Territories, has a runoff of 0.28 c.f.s. per square mile. According to the Atlas of Canada, the mean annual number of degree days above 42°F for the Reindeer River and Burntwood River basins is approximately 1700, while the corresponding figure for the South Seal River basin is approximately 1400, which is about the same as the Snare River basin. The mean annual total precipitation on the South Seal River basin is approximately 15 inches, which compares with 16 inches on the Reindeer River basin, 17 inches on the Burntwood River basin and 9 inches on the Snare River basin. Taking an average of these conditions, the runoff for the South Seal River basin was estimated at 0.45 c.f.s. per square mile. With a drainage area of 11,200 square miles tributary to Chipewayan Lake, an average discharge of 5050 c.f.s. would be expected at this point. Development of the vast storage potential on Big Sand Lake would result in a high utilization of flows for diversion purposes. Therefore, it is considered that an average diversion discharge of approximately 4500 c.f.s. could be obtained from the South Seal River. Available topographic information indicates that construction of a dam approximately 100 feet in height downstream of Shethanei Lake would make it possible to divert water from the North Seal River, as well, to Southern Indian Lake on the Churchill River. This would increase the drainage area tributary to the diversion point to approximately 18,200 square miles, with an average discharge of 8200 c.f.s. and a potential diversion of about 7500 c.f.s.

c) Conclusions

Preliminary indications suggest the Seal River basin to be an attractive source of water for diversion into the Churchill River. Further investigations should be initiated to assess the feasibility of diverting water from the Seal River basin for the purpose of increasing the power production of the proposed hydroelectric developments on the Burntwood River and Nelson River. This diversion could provide a partial replacement of flows to the currently proposed Churchill River diversion via the Burntwood River, if flows were diverted upstream at Frog Portage at some future date.

VII. SEQUENCE OF DEVELOPMENT OF PROPOSED DIVERSIONS

The sequence of development for this water plan will undoubtedly be dictated by economic considerations. None of the proposed diversions will be undertaken until the value of water for multi-purpose consumptive use exceeds its value for the production of hydro-electric power plus the cost of the diversion works necessary to make it available for consumptive use. This situation has already occurred in the southwestern United States, but it is likely to be a considerable length of time before we experience this occurrence in Western Canada. Neighbouring interests may, however, be willing to pay a sufficient price for this water in the near future.

When the demand for this water increases its value to the proper level, the sequence of development will again be governed by economic considerations. The project which requires the lowest initial expenditure to divert water will be the first to be constructed. Since the diversion works at Mossey Portage and Meadow Portage are required in order to provide any water to southern Manitoba, these would necessarily be the first to be constructed. Secondly, the diversion of the Churchill River would be constructed. Although the initial capital cost for this project would be greater than the cost of a pumping installation at Grand Rapids, the operational cost of pumping in the latter scheme makes the unit cost of water greater. Finally, the Grand Rapids pumping installation would be made. The South Seal River diversion, if it proves economical for the production of power on the Burntwood and Nelson Rivers would likely be scheduled simultaneously with the Sturgeon-Weir diversion in order to partially maintain generating capacity in the Manitoba electrical generating system. As referred to in V.1., the thesis by E. T. Wagner is intended to determine the minimum discharge requirement to maintain the firm capacity of the Nelson River Power Developments. Whether the water would be supplied from Lake Winnipeg or from another source, such as the Seal River would be decided by future investigations.

An alternative sequence of development could be influenced by the potential value of the Churchill River diversion via the Sturgeon-Weir River for the production of hydroelectric energy at presently developed hydroelectric installations. It may be found that the value of the power which could be produced at the Grand Rapids and Kelsey Generating Stations is sufficient to justify development of the Sturgeon-Weir diversion in a combination with the presently planned diversion via the Burntwood River. If this alternative development were followed, the construction of the diversion works at Mossey Portage, and Meadow Portage would divert the combined flows of the Saskatchewan River and Churchill River - approximately 40,000 c.f.s. in total - into the Lake Manitoba watershed. The installation of pumping capacity at Grand Rapids would be the final phase of this development. The development of the South Seal River diversion would likely coincide with the initial phase of this plan, which represents a considerable diminishing of flows to the Nelson River.

VIII. COST OF DIVERTED WATER

VIII. 1. Introduction

The total cost of the water which would be made available at Lake Manitoba from the proposed diversion schemes would be made up of two elements - the annual cost of the diversion works and the annual value of the energy foregone by diversion of water which would otherwise discharge through 125 feet of developed head at Grand Rapids, 56 feet of developed head at Island Falls and approximately 600 feet of head to be developed on the Nelson River during the next 25 years.

The annual cost of the diversion schemes consists of the annual charges applied to the development, expressed as a percentage of the capital investment and the cost of energy for any pumping which is required in the scheme. The annual charges on all schemes, consist of interest, depreciation, operation and maintenance, taxes, administration and insurance which amounts to 7.5 percent of the capital cost. The cost of pumping, at the proposed Grand Rapids development was based on an energy cost of 3 mills per kilowatt-hour.

Potential energy foregone by diversion of water was valued at 3 mills per kilowatt-hour, assuming that the Grand Rapids and Nelson River power plants can be placed in the peak of the future system load curve without loss of capacity benefits. If this is not true, a considerably higher value must be assigned to the energy lost from these plants. The energy foregone annually at the Island Falls Generating Station would have a value of approximately 2 million dollars. The energy foregone annually at the Grand Rapids Generating Station would have a value of approximately 5.0 million dollars. The value of the energy foregone on the Nelson

River would be approximately 76.5 million dollars per annum. In this last instance, it was assumed that Churchill River flows would otherwise produce power on the Nelson River by means of the proposed diversion via the Burntwood River.

VIII. 2. Unit Costs

Development of the Saskatchewan River Diversion to Lake Manitoba would convey 16,000,000 acre-feet per year to Lake Manitoba. The total capital cost of this diversion would be $48,000,000. Assuming annual charges of 7.5%, the annual cost of this scheme would be $3,600,000 plus $5,000,000 for energy foregone at Grand Rapids, plus $24,100,000 for energy foregone on the Nelson River. Thus, the total annual cost is $32,600,000 or $2.04 per acre foot.

Development of the Churchill River Diversion via the Sturgeon-Weir River would convey an additional 16,000,000 acre-feet of water annually to Lake Manitoba. The capital cost of this diversion would be $18,000,000, resulting in an annual cost of $1,300,000, which would be added to the annual energy loss at Island Falls worth $2,000,000 and the annual energy loss on the Nelson River worth $16,700,000. Thus, the incremental cost of water from the Sturgeon-Weir diversion would be $20,000,000 per year or $1.25 per acre-foot. The unit cost of water from this diversion combined with the Saskatchewan River diversion would be $1.64 per acre-foot at Lake Manitoba.

Development of the pumping installation at Grand Rapids as outlined previously would convey 21,000,000 acre-feet of water annually to Lake Manitoba. The capital cost of this scheme would be considered as the cost of conversion of the generating station, $22,000,000, plus the initial development cost of $130,000,000. This results in annual charges of $11,400,000 plus an annual pumping cost of $9,000,000 and an annual energy loss of $35,700,000 on the Nelson River. Thus, the incremental cost of water from the Grand Rapids pumping installation would be $56,100,000 per year or $2.67 per acre-foot. The unit cost of water from all three diversions combined would be $2.05 per acre-foot at Lake Manitoba.

IX. RECOMMENDATIONS AND CONCLUSIONS

1. From an engineering point of view, it would be feasible to develop the diversion schemes investigated in this thesis: diversion of the Churchill River via the Sturgeon-Weir River into the Saskatchewan River, diversion of the Saskatchewan River into Lake Manitoba, and diversion, by pumping at Grand Rapids of water from Lake Winnipeg into Cedar Lake and thence to Lake Manitoba.

2. Development of the three above mentioned diversions would convey 53,000,000 acre-feet per year to Lake Manitoba at a cost of $2.05 per acre-foot, while development of the first two diversions would convey 32,000,000 acre-feet per year at $1.64 per acre-foot.

3. It is recommended that an investigation be made of the Seal River diversion to assess its value for future Water Resources Planning.

4. It is recommended that a more detailed investigation be made of the three diversions outlined in point 1 of this chapter, to assess the effects of altering water levels and flows on human activity, fishing, forestry, mining and other other resources in the area.

5. As noted in Chapter VII, the Churchill River Diversion via the Sturgeon-Weir River would have immediate energy benefits at the Grand Rapids and Kelsey Generating Stations, as well as future benefits from Nelson River power development. Therefore, it would appear worthwhile to investigate co-ordination of two diversions on the Churchill River - the diversion via the

Burntwood to provide energy benefits now and to maintain the capacity of the Nelson power stations in the future when diversions are contemplated, and the diversion via the Sturgeon-Weir to provide energy benefits now and multi-purpose benefits in the future.

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APPENDIX I

RESERVOIR OPERATION FOR TOTAL DIVERSION SCHEME

ASSUMED CONSTANT OUTFLOW FROM L. WINNIPEGOSIS = 72,000 c.f.s.

a) Operation of Storage for Sturgeon - Weir Diversion

Assumptions

1. Operation of 13 feet of live storage on Reindeer Lake between elevations 100.0 and 113.0. (Corresponding approximately to Geodetic elevations 1093 and 1106). Storage capacity is 345,000 s.f.m.

2. 20,000 s.f.m. storage can be obtained from drawdown of reservoir area downstream of Reindeer Lake between elevations 1093 and 1085.

3. Maximum diverted flow would be 25,000 c.f.s., minimum 18,000 c.f.s.

4. Minimum spillage to Island Falls would be 300 c.f.s.

5. Rule Curve as follows:

Reservoir Elevation		Diversion Release
>110.4		25,000 c.f.s.
109.9 to 110.4	Rising limb hydrograph	25,000 c.f.s.
	Falling limb hydrograph	18,800 c.f.s.
101.9 to 109.9		18,800 c.f.s.
<101.9		18,000 c.f.s.

NOTE: Reindeer Lake Inflow was reconstructed by using Reindeer Lake Outflow, plus or minus the change in storage. Churchill River flow upstream of the confluence with the Reindeer River was reconstructed by using discharge of the Churchill River at Island Falls minus Reindeer River at the outlet of Reindeer Lake.

b) Operation of Storage for Regulation of Flows to Lake Manitoba

Assumptions

1. Regulation of 5 feet of storage on Cedar L. - L. Winnipegosis between elevations 829.5 and 835.0 would provide the required storage volume of 149,000 S.F.M.

2. Since there is no pumping requirement when there is storage in the upper 35,000 S.F.M. of the reservoir, the maximum H.W.L. during pumping at Grand Rapids would be 833.8.

c) Operation of Storage on Lake Winnipeg

Five feet of live storage on Lake Winnipeg between elevations 709 and 714 would provide the required pumping capacity at Grand Rapids during the critical dry period of record.

ASSUMED CONSTANT OUTFLOW FROM LAKE WINNIPEGOSIS - 72,000 c.f.s.

		c.f.s.											
Year	Month	Churchill R. @ Trade L.	Inflow Reindeer L.	Reindeer L. Elevation 112.00	Δ Storage Reindeer L.	Outflow Reindeer L.	Diverted Flow	Spillage to Island Falls	Saskatchewan River Flow	Pumping from L. Winnipeg	Inflow Cedar L.- L. Winnipegosis	Storage C.L. - L.W.	Cumulative Δ Storage
1930-	June	16,000	19,400	112.37	+.37	25,300	25,000	300	34,000	-	59,000	-13,000	-13,000
	July	13,200	8,400	112.23	-.14	"	"	"	41,700	-	66,700	- 5,300	-18,300
	Aug.	8,100	2,900	111.71	-.52	"	"	"	28,700	-	55,300	-16,700	-35,000
	Sept.	9,400	11,200	111.54	-.17	"	"	"	18,700	28,300	72,000	-	"
	Oct.	9,200	12,700	111.42	-.12	"	"	"	11,600	35,400	"	-	"
	Nov.	10,400	10,700	111.27	-.15	"	"	"	8,600	38,000	71,600	- 400	-35,400
	Dec.	10,200	11,400	111.13	-.14	"	"	"	4,700	"	67,700	- 4,300	-39,700
1931-	Jan.	9,200	6,700	110.79	-.34	"	"	"	3,900	"	66,900	- 5,100	-44,800
	Feb.	9,000	8,100	110.49	-.30	"	"	"	3,600	"	66,600	- 5,400	-50,200
	Mar.	8,300	9,800	110.23	-.26	"	"	"	4,200	"	67,200	- 4,800	-55,000
	Apr.	11,000	26,000	110.66	+.43	"	"	"	16,900	"	79,900	+ 7,900	-47,100
	May	14,900	22,500	111.10	+.44	"	"	"	15,600	"	78,600	+ 6,600	-40,500
	June	16,200	23,700	111.63	+.53	"	"	"	17,800	34,700	77,500	+ 5,500	-35,000
	July	17,300	20,900	112.10	+.47	"	"	"	36,900	10,100	72,000	-	"
	Aug.	17,500	17,500	112.46	+.36	"	"	"	28,800	18,200	"	-	"
	Sept.	17,900	16,700	112.80	+.34	"	"	"	22,700	24,300	"	-	"
	Oct.	18,900	16,500	113.00	+.20	29,900	"	4600	19,200	27,800	"	-	"
	Nov.	17,100	12,900	"	-	30,000	"	4700	11,300	35,700	"	-	"
	Dec.	14,100	16,500	"	-	30,600	"	5300	3,100	38,000	66,100	- 5,900	-40,900
1932-	Jan.	12,400	13,200	"	-	25,600	"	600	3,700	"	66,900	- 5,100	-46,000
	Feb.	9,900	16,000	"	-	25,900	"	900	4,700	"	67,900	- 4,100	-50,100
	Mar.	8,100	13,700	112.87	-.13	25,300	"	300	4,600	"	67,800	- 4,200	-54,300
	Apr.	9,000	15,900	112.86	-.01	"	"	12600	20,200	"	83,200	+11,200	-43,100
	May	15,900	25,800	113.00	+.14	37,900	"	37700	40,100	15,000	80,100	+ 8,100	-35,000
	June	22,400	40,300	"	-	62,700	"	25100	52,900	-	77,900	+ 5,900	-29,100
	July	23,900	26,200	"	-	50,100	"	29500	62,500	-	87,500	+15,500	-13,600
	Aug.	30,700	23,800	"	-	54,500	"	24900	37,200	-	62,200	- 9,800	-23,400
	Sept.	34,000	15,900	"	-	49,900	"	14900	28,300	7,100	60,400	-11,600	-35,000
	Oct.	27,300	12,600	"	-	39,900	"	7800	17,900	29,100	72,000	-	"
	Nov.	18,900	13,900	"	-	32,800	"	5100	12,400	34,600	"	-	"
	Dec.	13,400	16,700	"	-	30,100	"	300	6,400	38,000	69,400	- 2,600	-37,600
1933-	Jan.	10,400	13,700	112.96	-.04	25,300	"	"	6,000	"	69,000	- 3,000	-40,600
	Feb.	8,800	8,700	112.67	-.29	"	"	"	5,600	"	68,600	- 3,400	-44,000
	Mar.	9,200	10,200	112.45	-.22	"	"	"	5,300	"	68,300	- 3,700	-47,700

			112.45									
1933-April	8,800	8,100	112.14	-.31	25,300	25,000	300	18,000	38,000	81,000	+9,000	-38,700
May	20,000	37,900	113.00	+.86	34,400	"	9,400	50,300	400	75,700	+3,700	-35,000
June	26,900	33,800	"	-	60,700	"	35,700	53,700	-	78,700	+6,700	-28,300
July	23,300	27,000	"	-	50,300	"	25,300	53,400	-	78,400	+6,400	-21,900
Aug.	24,200	8,500	"	-	32,700	"	7,700	32,300	1,600	58,900	-13,100	-35,000
Sept.	22,800	8,200	"	-	31,000	"	6,000	24,200	22,800	72,000	-	"
Oct.	19,800	6,500	"	-	26,300	"	1,300	14,900	32,100	"	-	"
Nov.	16,900	11,600	"	-	28,500	"	3,500	11,400	35,600	"	-	"
Dec.	15,100	8,000	112.92	-.08	25,300	"	300	8,600	38,000	71,600	- 400	-35,400
1934-Jan.	13,700	6,200	112.72	-.20	"	"	"	6,100	"	69,100	-2,900	-38,300
Feb.	12,700	9,700	112.54	-.18	"	"	"	7,100	"	70,100	-1,900	-40,200
Mar.	11,700	7,400	112.31	-.23	"	"	"	8,300	"	71,300	- 700	-40,900
Apr.	11,800	5,500	112.02	-.29	"	"	"	23,900	29,000	77,900	+5,900	-35,000
May	21,900	13,200	112.38	+.36	"	"	"	54,800	-	79,800	+7,800	-27,200
June	35,000	38,500	113.00	+.62	56,600	"	31,600	50,100	-	75,100	+3,100	-24,100
July	33,100	28,800	"	-	61,900	"	36,900	56,800	-	81,800	+9,800	-14,300
Aug.	25,400	20,800	"	-	46,200	"	21,200	35,500	-	60,500	-11,500	-25,800
Sept.	19,900	20,800	"	-	40,700	"	15,700	23,200	14,600	62,800	-9,200	-35,000
Oct.	17,900	13,400	"	-	31,300	"	6,300	16,600	30,400	72,000	-	"
Nov.	16,300	18,000	"	-	34,300	"	9,300	15,000	32,000	"	-	"
Dec.	13,200	15,400	"	-	28,600	"	3,600	10,400	36,600	"	-	"
1935-Jan.	11,700	12,700	112.97	-.03	25,300	"	300	6,800	38,000	69,800	-2,200	-37,200
Feb.	11,100	10,900	112.85	-.12	"	"	"	5,100	"	68,100	-3,900	-41,100
Mar.	9,100	7,000	112.51	-.34	"	"	"	7,500	"	70,500	-1,500	-42,600
Apr.	10,200	7,800	112.24	-.27	"	"	"	19,000	35,600	79,600	+7,600	-35,000
May	17,200	36,000	113.00	+.76	32,400	"	7,400	37,300	9,700	72,000	-	"
June	19,800	18,900	"	-	38,700	"	13,700	38,200	8,800	"	-	"
July	17,200	2,100	112.78	-.22	25,300	"	300	48,900	-	73,900	+1,900	-33,100
Aug.	16,700	8,100	112.76	-.02	"	"	"	44,200	900	70,100	-1,900	-35,000
Sept.	15,700	12,700	112.87	+.11	"	"	"	22,200	24,800	72,000	-	"
Oct.	13,400	10,900	112.83	-.04	"	"	"	11,700	35,300	"	-	"
Nov.	12,600	12,100	112.81	-.02	"	"	"	5,500	38,000	68,500	-3,500	-38,500
Dec.	10,000	12,700	112.71	-.10	"	"	"	4,700	"	67,700	-4,300	-42,800
1936-Jan.	9,200	11,500	112.54	-.17	"	"	"	3,600	"	66,600	-5,400	-48,200
Feb.	16,800	8,400	"	-	"	"	"	3,200	"	66,200	-5,800	-54,000
Mar.	5,900	5,600	112.03	-.51	"	"	"	"	"	"	"	-59,800
April	7,500	9,900	111.74	-.29	"	"	"	15,400	"	78,400	+6,400	-53,400
						"						

May	12,900	11,500	111.70	-.04	25,300	25,000	300	56,400	9,000	90,400	+18,400	-35,000
June	13,300	11,600	111.69	-.01	"	"	"	44,800	2,200	72,000	–	"
July	12,800	29,100	112.30	+.61	"	"	"	30,900	16,100	"	–	"
Aug.	10,400	16,200	112.35	+.05	"	"	"	18,700	28,300	"	–	"
Sept.	8,800	9,400	112.09	-.26	"	"	"	17,200	29,800	"	–	"
Oct.	9,200	3,800	111.64	-.45	"	"	"	9,200	37,800	"	–	"
Nov.	7,800	9,600	111.35	-.29	"	"	"	5,800	38,000	68,200	- 3,200	-38,200
Dec.	7,100	6,900	110.94	-.41	"	"	"	3,100	"	66,100	- 5,900	-44,100
1937-Jan.	5,500	5,600	110.42	-.52	"	"	"	2,100	"	65,100	- 6,900	-51,000
Feb.	3,400	7,100	110.11	-.31	19,100	18,800	"	2,000	"	58,800	-13,200	-64,200
Mar.	2,800	6,400	109.75	-.36	"	"	"	2,300	"	59,100	-12,900	-77,100
Apr.	5,400	11,000	109.66	-.09	"	"	"	17,900	"	74,700	+ 2,700	-74,400
May	7,000	15,500	109.79	+.13	"	"	"	22,500	"	79,300	+ 7,300	-67,100
June	6,000	16,900	109.84	+.15	"	"	"	22,100	"	78,900	+ 6,900	-60,200
July	4,500	16,600	109.92	+.08	"	"	"	32,900	"	89,700	+17,700	-42,500
Aug.	5,700	12,200	109.89	-.03	"	"	"	25,100	35,600	79,500	+ 7,500	-35,000
Sept	4,000	8,000	109.64	-.25	"	"	"	13,700	38,000	70,500	- 1,500	-36,500
Oct.	2,900	1,000	109.08	-.56	"	"	"	10,700	"	67,500	- 4,500	-41,000
Nov.	3,300	3,100	108.62	-.46	"	"	"	8,500	"	65,300	- 6,700	-47,700
Dec.	3,100	7,000	108.30	-.32	"	"	"	3,600	"	60,400	-11,600	-59,300
1938-Jan.	3,000	3,900	107.86	-.44	"	"	"	3,500	"	60,300	-11,700	-71,000
Feb.	2,700	6,500	107.50	-.36	"	"	"	2,400	"	59,200	-12,800	-83,800
Mar.	2,500	5,500	107.12	-.38	"	"	"	3,300	"	60,100	-11,900	-95,700
Apr.	"	6,300	107.13	-.38	"	"	"	20,200	"	77,000	+ 5,000	-90,700
May	5,600	28,000	107.68	+.53	"	"	"	23,000	"	79,800	+ 7,800	-82,900
June	4,500	26,800	108.15	+.45	"	"	"	36,100	"	92,900	+20,900	-62,000
July	8,700	23,500	108.65	+.48	"	"	"	48,000	30,200	97,000	+25,000	-37,000
Aug.	6,900	12,300	108.67	–	"	"	"	31,600	23,600	74,000	+ 2,000	-35,000
Sept.	5,500	8,200	108.49	-.20	"	"	"	22,500	30,700	72,000	–	"
Oct.	4,600	1,600	108.04	-.47	"	"	"	15,000	38,000	71,800	- 200	-35,200
Nov.	3,800	5,200	107.69	-.37	"	"	"	5,200	"	62,200	- 9,800	-45,000
Dec.	3,900	9,100	107.49	-.22	"	"	"	3,000	"	60,000	-12,000	-57,100
1939-Jan.	3,400	5,100	107.12	-.39	"	"	"	2,900	"	59,900	-12,100	-69,100
Feb.	2,700	5,700	106.75	-.39	"	"	"	2,400	"	59,400	-12,600	-81,700
Mar.	2,600	6,500	106.41	-.35	"	"	"	2,800	"	59,800	-12,200	-93,900
Apr.	2,800	7,200	106.10	-.33	"	"	"	20,500	"	77,300	+ 5,300	-88,600
May	8,100	34,500	106.98	+.86	"	"	"	24,300	"	81,100	+ 9,100	-79,500

June	11,100	23,300	107.54	+.56	19,100	18,800	300	24,900	38,000	81,700	+ 9,700	-69,800
July	12,700	15,300	107.87	+.33	"	"	"	50,200	28,000	97,000	+25,000	-44,800
Aug.	9,000	23,300	108.35	+.48	"	"	"	28,900	34,100	81,800	+ 9,800	-35,000
Sept.	8,300	8,500	108.27	-.08	"	"	"	16,300	36,900	72,000	-	"
Oct.	6,600	14,400	108.20	-.07	"	"	"	10,700	38,000	67,500	- 4,500	-39,500
Nov.	7,400	8,600	108.09	-.11	"	"	"	5,000	"	61,800	-10,200	-49,700
Dec.	6,800	8,300	108.02	-.07	"	"	"	6,800	"	63,600	- 8,400	-58,100
1940-Jan.	5,300	9,700	107.87	-.15	"	"	"	3,500	"	60,300	-11,700	-69,800
Feb.	5,900	5,300	107.58	-.29	"	"	"	2,400	"	59,200	-12,800	-82,600
Mar.	4,400	5,700	107.25	-.33	"	"	"	2,700	"	59,500	-12,500	-95,100
Apr.	3,900	3,700	106.97	-.28	"	"	"	14,400	"	71,200	- 800	-95,900
May	6,300	20,800	107.26	+.29	"	"	"	44,200	34,000	97,000	+25,000	-70,900
June	6,200	16,600	107.40	+.14	"	"	"	33,500	38,000	90,300	+18,300	-52,600
July	5,800	8,000	107.21	-.19	"	"	"	24,300	"	81,100	+ 9,100	-43,500
Aug.	2,800	1,400	106.66	-.55	"	"	"	21,300	"	78,100	+ 6,100	-37,400
Sept	2,300	2,400	106.13	-.53	"	"	"	14,700	"	71,500	- 500	-37,900
Oct.	1,100	5,000	105.65	-.48	"	"	"	15,000	"	71,800	- 200	-38,100
Nov.	2,300	2,700	105.13	-.52	"	"	"	6,700	"	63,700	- 8,300	-46,400
Dec.	"	4,800	104.69	-.44	"	"	"	4,100	"	61,100	-10,900	-57,300
1941-Jan.	1,500	3,900	104.19	-.50	"	"	"	3,600	"	60,600	-11,400	-68,700
Feb.	1,600	4,700	103.72	-.47	"	"	"	2,700	"	59,700	-12,300	-81,000
Mar.	1,700	17,500	"	-	"	"	"	"	"	"	"	-93,300
Apr.	1,900	22,400	103.91	+.19	"	"	"	21,900	"	78,700	+ 6,700	-86,600
May	3,500	36,400	104.67	+.76	"	"	"	13,700	"	70,500	- 1,500	-88,100
June	3,000	30,400	105.19	+.52	"	"	"	12,700	"	69,500	- 2,500	-90,600
July	3,700	34,600	105.89	+.70	"	"	"	19,100	"	75,900	+ 3,900	-86,700
Aug.	2,700	9,300	105.63	-.26	"	"	"	16,600	"	73,400	+ 1,400	-85,300
Sept.	2,900	8,800	105.36	-.27	"	"	"	14,600	"	71,400	- 600	-85,900
Oct.	2,600	14,200	105.28	-.08	"	"	"	9,700	"	66,500	- 5,500	-91,400
Nov.	2,500	10,000	105.04	-.24	"	"	"	9,400	"	66,200	- 5,800	-97,200
Dec.	2,300	12,900	104.90	-.14	"	"	"	3,000	"	59,800	-12,200	-109,400
1942-Jan.	2,100	8,200	104.58	-.32	"	"	"	2,000	"	58,800	-13,200	-122,600
Feb.	1,800	6,800	104.20	-.38	"	"	"	2,200	"	59,000	-13,000	-135,600
Mar.	1,500	11,600	103.98	-.22	"	"	"	2,400	"	59,200	-12,800	-148,400
Apr.	2,800	8,700	103.70	-.28	"	"	"	15,000	"	71,800	- 200	-148,600
May	4,200	29,000	104.22	+.52	"	"	"	19,000	"	75,800	+ 3,800	-144,800
June	6,700	15,400	104.33	+.11	"	"	"	40,500	37,700	97,000	+25,000	-119,800

1942-July	7,800	16,700	104.52	+.19	19,100	18,800	300	57,400	20,800	97,000	+25,000	-94,800
Aug.	5,100	10,600	104.40	-.12	"	"	"	53,200	25,000	"	"	-69,800
Sept	3,100	700	103.84	-.56	"	"	"	33,300	38,000	90,100	+18,100	-51,700
Oct.	2,000	400	103.23	-.61	"	"	"	21,600	"	78,400	+ 6,400	-45,300
Nov.	3,100	5,300	102.84	-.39	"	"	"	11,200	"	68,000	- 4,000	-49,300
Dec.	2,000	4,300	102.37	-.47	"	"	"	6,300	"	63,100	- 8,900	-58,200
1943-Jan	2,200	4,000	101.90	-.47	"	"	"	5,600	"	62,400	- 9,600	-67,800
Feb.	1,800	1,800	101.36	-.54	18,300	18,000	"	4,700	"	60,700	-11,300	-79,100
Mar.	1,500	900	100.78	-.58	"	"	"	5,200	"	61,200	-10,800	-89,900
Apr.	2,800	4,000	100.36	-.42	"	"	"	36,400	"	92,400	+20,400	-69,500
May	5,400	19,900	100.62	+.26	"	"	"	48,200	30,800	97,000	+25,000	-44,500
June	6,300	20,300	100.92	+.30	"	"	"	35,600	27,900	81,500	+ 9,500	-35,000
July	7,300	25,500	101.45	+.53	"	"	"	50,200	3,800	72,000	-	"
Aug.	7,500	22,800	101.89	+.44	"	"	"	38,400	15,600	"	-	"
Sept	5,900	9,900	101.80	-.09	"	"	"	22,300	31,700	"	-	"
Oct.	6,000	5,000	101.53	-.27	"	"	"	12,200	38,000	68,200	- 3,800	-38,800
Nov.	6,100	10,000	101.45	-.08	"	"	"	9,600	"	65,600	- 6,400	-45,200
Dec.	5,400	8,600	101.29	-.16	"	"	"	4,300	"	60,300	-11,700	-56,900
1944-Jan.	5,000	7,400	101.07	-.22	"	"	"	3,900	"	59,900	-12,100	-69,000
Feb.	4,100	4,100	100.70	-.37	"	"	"	3,700	"	59,700	-12,300	-81,300
Mar.	4,300	3,200	100.31	-.39	"	"	"	3,600	"	59,600	-12,400	-93,700
Apr.	5,600	4,300	100.00	-.31	"	"	"	21,200	"	77,200	+ 5,200	-88,500
May	6,200	10,900	*-1100	-1100	"	"	"	17,500	"	73,500	+ 1,500	-87,000
June	6,100	6,700	-6600	-5500	"	"	"	31,100	"	87,100	+15,100	-71,900
July	6,000	13,300	-5500	+1000	"	"	"	52,000	27,000	97,000	+25,000	-46,900
Aug.	5,800	23,600	100.21	+.41	"	"	"	38,600	27,300	83,900	+11,900	-35,000
Sept.	5,900	22,400	100.58	+.37	"	"	"	27,500	26,500	72,000	-	"
Oct.	6,600	12,300	100.60	+.02	"	"	"	15,400	38,000	71,400	- 600	-35,600
Nov.	7,800	5,700	100.42	-.18	"	"	"	7,600	"	63,600	- 8,400	-44,000
Dec.	7,300	10,800	100.41	-.01	"	"	"	4,800	"	60,800	-11,200	-55,200
1945-Jan.	7,000	2,900	100.10	-.31	"	"	"	3,500	"	59,500	-12,500	-67,700
Feb.	6,700	4,400	-4400	-.26	"	"	"	4,200	"	60,200	-11,800	-79,500
Mar.	5,700	5,700	-11,200	-6800	"	"	"	4,700	"	60,700	-11,300	-90,800
Apr.	5,500	12,700	"	-	"	"	"	18,100	"	74,100	+ 2,100	-88,700
May	8,700	2,500	-18,300	-7100	"	"	"	29,100	"	85,100	+13,100	-75,600
June	10,400	17,400	-8,700	+9600	"	"	"	42,600	36,400	97,000	+25,000	-50,600
July	"	14,900	-1,600	+7100	"	"	"	49,500	20,100	87,600	+15,600	-35,000

*Storage volume D./S. Reindeer Lake.

1945-Aug.	8,200	9,800	-1900	-300	18,300	18,000	300	30,900	23,100	72,000	-	-35,000
Sept.	6,900	11,400	"	-	"	"	"	20,600	33,400	"	-	"
Oct.	13,500	11,200	100.16	+.23	"	"	"	18,600	35,400	"	-	"
Nov.	13,700	10,400	100.37	+.21	"	"	"	10,100	38,000	66,100	- 5,900	-40,900
Dec.	11,300	10,500	100.50	+.13	"	"	"	6,800	"	62,800	- 9,200	-50,100
1946-Jan	9,500	10,300	100.56	+.06	"	"	"	6,100	"	62,100	- 9,900	-60,000
Feb.	8,000	2,100	100.26	-.30	"	"	"	6,000	"	62,000	-10,000	-70,000
Mar.	7,200	7,200	100.12	-.14	"	"	"	6,800	"	62,800	- 9,200	-79,200
Apr.	8,000	13,500	100.24	+.12	"	"	"	35,500	"	91,500	+19,500	-59,700
May	13,700	11,700	100.50	+.26	"	"	"	25,300	"	81,300	+ 9,300	-50,400
June	15,100	20,500	101.13	+.63	"	"	"	34,400	35,000	87,400	+15,400	-35,000
July	"	18,600	101.69	+.56	"	"	"	43,100	5,900	72,000	-	"
Aug.	9,700	400	101.39	-.30	"	"	"	29,400	24,600	"	-	"
Sept	9,900	11,800	101.51	+.12	"	"	"	20,100	33,900	"	-	"
Oct.	13,600	400	101.35	-.16	"	"	"	15,200	38,000	71,200	- 800	-35,800
Nov.	7,100	5,400	101.14	-.21	"	"	"	8,700	"	64,700	- 7,300	-43,100
Dec.	5,800	7,600	100.96	-.18	"	"	"	4,200	"	60,200	-11,800	-54,900
1947-Jan.	5,300	500	100.50	-.46	"	"	"	5,800	"	61,800	-10,200	-65,100
Feb.	5,100	12,400	100.47	-.03	"	"	"	5,400	"	61,400	-10,600	-75,700
Mar.	4,700	13,600	"	-	"	"	"	6,100	"	62,100	- 9,900	-85,600
Apr.	4,400	8,900	100.29	-.18	"	"	"	28,900	"	84,900	+12,900	-72,700
May	14,200	800	100.17	-.12	"	"	"	51,500	27,500	97,000	+25,000	-47,700
June	17,700	6,700	100.39	+.22	"	"	"	46,900	19,800	84,700	+12,700	-35,000
July	17,000	43,500	101.91	+1.52	19,100	18,800	"	46,800	6,400	72,000	-	"
Aug.	19,900	1,500	101.99	+.08	"	"	"	30,100	23,100	"	-	"
Sept	15,300	24,900	102.76	+.77	"	"	"	23,900	29,300	"	-	"
Oct.	16,400	42,700	104.23	+1.47	"	"	"	22,700	30,500	"	-	"
Nov.	16,700	23,000	104.98	+.75	"	"	"	16,600	36,600	"	-	"
Dec.	14,500	15,300	105.37	+.39	"	"	"	10,000	38,000	66,800	- 5,200	-40,200
1948-Jan.	12,400	10,000	105.49	+.12	"	"	"	9,300	"	66,100	- 5,900	-46,100
Feb.	10,100	7,000	105.42	-.07	"	"	"	7,200	"	64,000	- 8,000	-54,100
Mar.	9,500	6,400	105.30	-.12	"	"	"	6,400	"	63,200	- 8,800	-62,900
Apr.	9,100	7,100	105.19	-.11	"	"	"	11,700	"	68,500	- 3,500	-66,400
May	15,700	18,700	105.75	+.56	"	"	"	79,600	-	98,400	+26,400	-40,000
June	12,200	16,600	106.80	+1.05	300	-	"	100,700	-	100,700	+28,700	-11,300
July	13,800	14,400	107.13	+.33	19,100	18,800	"	78,600	-	97,400	+25,400	FULL
Aug.	18,800	9,300	107.46	+.33	"	"	"	51,400	-	70,200	- 1,800	- 1,800

1948-Sept	15,600	20,500	108.08	+.62	19,100	18,800	300	32,700	-	51,500	-20,500	-22,300
Oct.	13,200	9,800	108.22	+.14	"	"	"	15,400	25,100	59,300	-12,700	-35,000
Nov.	11,000	6,200	108.15	-.07	"	"	"	7,000	38,000	63,800	- 8,200	-43,200
Dec.	9,800	10,800	108.21	+.06	"	"	"	3,700	"	60,500	-11,500	-54,700
1949-Jan.	8,300	8,100	108.11	-.10	"	"	"	3,100	"	59,900	-12,100	-66,800
Feb.	7,400	4,800	107.86	-.25	"	"	"	2,700	"	59,500	-12,500	-79,300
Mar.	7,200	3,100	107.54	-.32	"	"	"	3,600	"	60,400	-11,600	-90,900
Apr.	7,500	9,600	107.47	-.07	"	"	"	25,100	"	81,900	+ 9,900	-81,000
May	11,200	34,100	108.43	+.96	"	"	"	17,700	"	74,500	+ 2,500	-78,500
June	22,100	44,300	109.93	+1.50	25,300	25,000	"	27,900	"	90,900	+18,900	-59,600
July	22,800	33,900	111.08	+1.15	"	"	"	24,800	"	87,800	+15,800	-43,800
Aug.	24,200	28,300	112.08	+1.00	"	"	"	25,200	30,600	80,800	+ 8,800	-35,000
Sept	22,500	11,400	112.39	+.31	"	"	"	15,200	31,800	72,000	-	"
Oct.	19,300	16,700	112.78	-.39	"	"	"	10,200	36,800	"	-	"
Nov.	13,600	17,200	112.98	-.20	"	"	"	11,400	35,600	"	-	"
Dec.	10,800	15,400	113.00	-.02	25,700	"	700	4,200	38,000	67,200	- 4,800	-39,800
1950-Jan.	9,000	6,700	112.65	-.35	25,300	"	300	3,400	"	66,400	- 5,600	-45,400
Feb.	7,400	9,100	112.33	-.32	"	"	"	4,300	"	67,300	- 4,700	-50,100
Mar.	6,600	3,600	111.78	-.55	"	"	"	4,200	"	67,200	- 4,800	-54,900
Apr.	"	6,000	111.31	-.47	"	"	"	15,700	"	78,700	+ 6,700	-48,200
May	7,900	26,700	111.65	+.34	"	"	"	33,800	26,400	85,200	+13,200	-35,000
June	13,800	19,800	111.95	+.30	"	"	"	29,800	17,200	72,000	-	"
July	12,800	17,300	112.13	+.18	"	"	"	49,200	-	74,200	+ 2,200	-32,800
Aug.	11,500	9,600	111.98	-.15	"	"	"	37,300	7,500	69,800	- 2,200	-35,000
Sept	11,000	11,300	111.87	-.11	"	"	"	21,400	25,600	72,000	-	"
Oct.	8,700	9,100	111.60	-.27	"	"	"	13,100	33,900	"	-	"
Nov.	7,000	13,300	111.42	-.18	"	"	"	7,600	38,000	70,600	- 1,400	-36,400
Dec.	7,900	11,000	111.19	-.23	"	"	"	5,300	"	68,300	- 3,700	-40,100
1951-Jan.	7,300	7,900	110.82	-.37	"	"	"	6,200	"	69,200	- 2,800	-42,900
Feb.	6,200	4,100	110.27	-.55	"	"	"	5,500	"	68,500	- 3,500	-46,400
Mar.	5,900	4,600	109.73	-.54	"	"	"	5,600	"	68,600	- 3,400	-49,800
Apr.	6,100	5,700	109.46	-.27	19,100	18,800	"	26,800	"	83,600	+11,600	-38,200
May	12,000	36,600	110.31	+.85	25,300	25,000	"	53,300	-	78,300	+ 6,300	-31,900
June	17,000	24,400	110.90	+.59	"	"	"	56,100	-	81,100	+ 9,100	-22,800
July	15,400	16,100	111.13	+.23	"	"	"	61,800	-	86,800	+14,800	- 8,000
Aug.	16,900	11,100	111.23	+.10	"	"	"	57,000	-	82,000	+10,000	FULL
Sept	15,300	4,600	111.03	-.20	"	"	"	45,700	-	70,700	- 1,300	- 1,300

1951-Oct.	14,300	3,400	110.75	-.28	25,300	25,000	300	39,300	-	64,300	- 7,700	- 9,000
Nov.	11,600	3,900	110.39	-.36	"	"	"	25,300	-	50,300	-21,700	-30,700
Dec.	9,900	7,600	110.10	-.29	"	"	"	14,000	28,700	67,700	- 4,300	-35,000
1952-Jan.	8,400	3,500	109.61	-.49	"	"	"	7,500	38,000	70,500	- 1,500	-36,500
Feb.	7,900	4,000	109.35	-.26	19,100	18,800	"	8,100	"	64,900	- 7,100	-43,600
Mar.	7,100	2,800	109.01	-.34	"	"	"	8,500	"	65,300	- 6,700	-50,300
Apr.	7,900	8,100	108.90	-.11	"	"	"	42,200	26,300	87,300	+15,300	-35,000
May	7,700	11,100	108.89	-.01	"	"	"	64,900	-	83,700	+11,700	-23,300
June	9,200	20,600	109.28	+.39	"	"	"	48,100	-	66,900	- 5,100	-28,400
July	13,800	17,100	109.71	+.43	"	"	"	65,100	-	83,900	+11,900	-16,300
Aug.	13,000	7,800	109.77	+.06	"	"	"	52,500	-	71,300	- 700	-17,000
Sept.	13,100	15,300	109.99	+.22	"	"	"	32,300	2,900	90,000	+18,000	-35,000
Oct.	11,700	11,300	109.91	-.08	25,300	25,000	"	18,700	28,300	72,000	-	"
Nov.	11,600	12,900	109.88	-.03	"	"	"	13,500	33,500	"	-	"
Dec.	9,800	12,000	109.98	+.10	19,100	18,800	"	5,400	38,000	62,200	- 9,800	-44,800
1953-Jan.	8,200	6,400	109.59	-.39	25,300	25,000	"	4,800	"	67,800	- 4,200	-49,000
Feb.	8,100	6,900	109.44	-.15	19,100	18,800	"	4,500	"	61,300	-10,700	-59,700
Mar.	7,100	3,000	109.11	-.33	"	"	"	5,600	"	62,600	- 9,600	-69,300
Apr.	7,000	7,200	108.93	-.18	"	"	"	18,100	"	74,900	+ 2,900	-66,400
May	8,500	13,300	108.99	+.06	"	"	"	43,100	35,100	97,000	+25,000	-41,400
June	7,800	17,000	109.19	+.20	"	"	"	57,600	2,000	65,600	- 6,400	-35,000
July	8,100	11,400	109.20	+.01	"	"	"	72,900	-	91,700	+19,700	-15,300
Aug.	7,500	7,300	109.04	-.16	"	"	"	52,800	-	71,600	- 400	-15,700
Sept	6,900	14,200	109.11	+.07	"	"	"	36,000	-	79,200	+ 7,200	-32,900
Oct.	7,400	12,400	109.14	+.03	"	"	"	18,200	32,900	69,900	- 2,100	-35,000
Nov.	9,400	9,100	109.11	-.03	"	"	"	11,300	38,000	68,100	- 3,900	-38,900
Dec.	8,800	9,800	109.09	-.02	"	"	"	5,100	"	61,900	-10,100	-49,000
1954-Jan.	7,800	11,100	109.08	-.01	"	"	"	4,700	"	61,500	-10,500	-59,500
Feb.	7,300	4,100	108.80	-.28	"	"	"	"	"	"	"	-70,000
Mar.	6,800	4,300	108.51	-.29	"	"	"	6,600	"	63,400	- 8,600	-78,600
Apr.	6,500	4,700	108.22	-.29	"	"	"	10,700	"	67,500	- 4,500	-83,100
May	8,700	16,500	108.44	+.22	"	"	"	44,700	33,500	97,000	+25,000	-58,100
June	13,200	21,000	108.99	+.55	"	"	"	66,300	10,000	95,100	+23,100	-35,000
July	16,000	21,700	109.67	+.68	"	"	"	73,200	-	92,000	+20,000	-15,000
Aug.	24,100	6,600	110.10	+.43	"	"	"	60,000	-	78,800	+ 6,800	- 8,200
Sept.	30,000	5,000	110.46	+.36	25,300	25,000	"	69,800	-	94,800	+22,800	FULL
Oct.	21,800	10,400	110.71	+.25	"	"	"	59,400	-	81,400	-	"

1954-Nov.	18,900	3,900	110.62	-.09	25,300	25,000	300	40,600	-	65,600	- 6,400	- 6,400
Dec.	17,800	11,900	110.78	+.16	"	"	"	28,800	-	60,200	-11,800	-18,200
1955-Jan.	14,600	7,700	110.67	-.11	"	"	"	13,000	7,200	55,200	-16,800	-35,000
Feb.	13,100	9,200	110.56	-.11	"	"	"	12,200	34,800	72,000	-	"
Mar.	11,700	3,100	110.18	-.38	"	"	"	9,700	37,300	"	-	"
Apr.	14,400	7,100	110.04	-.14	"	"	"	40,900	6,100	"	-	"
May	28,400	29,300	111.23	+1.19	"	"	"	64,100	-	89,100	+17,100	-17,900
June	24,500	17,200	111.83	+.60	"	"	"	66,200	-	91,200	+19,200	FULL
July	23,300	7,200	112.02	+.19	"	"	"	57,300	-	82,300	-	FULL
Aug.	18,800	9,000	112.11	+.09	"	"	"	42,300	-	67,300	- 4,700	- 9,100
Sept	15,500	0	111.75	-.36	"	"	"	21,300	-	46,300	-25,700	-34,800
Oct.	11,800	2,600	111.35	-.40	"	"	"	15,000	31,800	71,800	- 200	-35,000
Nov.	12,800	5,100	111.08	-.27	"	"	"	5,800	38,000	68,800	- 3,200	-38,200
Dec.	11,600	5,900	110.83	-.25	"	"	"	5,100	"	68,100	- 3,900	-42,100
1956-Jan.	10,500	3,900	110.43	-.40	"	"	"	5,300	"	68,300	- 3,700	-45,800
Feb.	9,500	2,400	109.87	-.56	"	"	"	6,200	"	69,200	- 2,800	-48,600
Mar.	8,700	3,400	109.61	-.26	19,100	18,800	"	6,500	"	63,300	- 8,700	-57,300
Apr.	"	5,200	109.42	-.19	"	"	"	21,900	"	78,700	+ 6,700	-50,600
May	12,400	10,500	109.56	+.14	"	"	"	69,100	-	87,900	+15,900	-34,700
June	10,600	12,700	109.71	+.15	"	"	"	62,100	-	80,900	+ 8,900	-25,800
July	11,000	4,300	109.57	-.14	"	"	"	50,500	-	69,300	- 2,700	-28,500
Aug.	12,800	3,100	109.45	-.12	"	"	"	37,800	8,900	65,500	- 6,500	-35,000
Sept	11,100	0	109.46	-.29	"	"	"	24,200	29,000	72,000	-	"
Oct.	10,500	100	108.85	-.31	"	"	"	16,600	36,600	"	-	"
Nov.	10,200	4,300	108.68	-.17	"	"	"	10,800	38,000	67,600	- 4,400	-39,400
Dec.	9,500	5,200	108.52	-.16	"	"	"	5,500	"	62,300	- 9,700	-49,100
1957-Jan.	9,200	3,000	108.27	-.25	"	"	"	4,600	"	61,400	-10,600	-59,700
Feb.	9,300	1,000	107.95	-.32	"	"	"	3,400	"	60,200	-11,800	-71,500
Mar.	8,800	3,200	107.69	-.26	"	"	"	4,400	"	61,200	-10,800	-82,300
Apr.	9,400	4,800	107.51	-.18	"	"	"	20,300	"	77,100	+ 5,100	-77,200
May	16,600	23,300	108.27	+.76	"	"	"	52,500	25,700	97,000	+25,000	-52,200
June	22,100	23,100	109.23	+.96	"	"	"	48,200	22,200	89,200	+17,200	-35,000
July	21,700	20,500	110.08	+.85	"	"	"	32,200	21,000	72,000	-	"
Aug.	20,500	13,600	110.40	-.32	25,000	25,000	"	20,500	26,500	"	-	"
Sept	15,400	14,700	110.58	+.18	"	"	"	18,200	28,800	"	-	"
Oct.	12,500	9,200	110.45	-.13	"	"	"	13,300	33,700	"	-	"
Nov.	11,100	9,000	110.26	-.19	"	"	"	13,500	33,500	"	-	"

1957-Dec.	10,400	8,700	110.03	-.23	25,300	25,000	300	7,300	38,000	70,300	- 1,700	-36,700
1958-Jan.	10,000	5,000	109.65	-.38	"	"	"	5,400	"	68,400	- 3,600	-40,300
Feb.	9,200	5,600	109.49	-.16	19,100	18,800	"	5,600	"	62,400	- 9,600	-49,900
Mar.	9,100	3,700	109.26	-.23	"	"	"	6,900	"	65,700	- 6,300	-56,200
Apr.	12,600	9,000	109.35	+.09	"	"	"	37,400	37,000	93,200	+21,200	-35,000
May	16,300	24,400	109.91	+.56	25,300	25,000	"	42,600	4,400	72,000	-	"
June	17,900	15,600	110.21	+.30	"	"	"	42,500	4,500	"	-	"
July	17,400	15,400	110.48	+.27	"	"	"	42,000	5,000	"	-	"
Aug.	14,500	10,600	110.46	-.02	"	"	"	31,900	15,100	"	-	"
Sept	"	10,400	110.44	-.02	"	"	"	17,400	29,600	"	-	"
Oct.	14,000	11,200	"	-	"	"	"	12,700	35,300	"	-	"
Nov.	13,400	9,500	110.35	-.09	"	"	"	7,900	38,000	70,900	- 1,100	-36,100
Dec.	12,300	"	110.22	-.13	"	"	"	4,400	"	67,400	- 4,600	-40,700
1959-Jan.	10,600	6,700	109.93	-.29	"	"	"	5,400	"	68,400	- 3,600	-44,300
Feb.	9,500	5,100	109.54	-.39	"	"	"	5,000	"	68,000	- 4,000	-48,300
Mar.	"	2,600	109.28	-.26	19,100	18,800	"	5,600	"	62,400	- 9,600	-57,900
Apr.	10,300	4,000	109.10	-.18	"	"	"	33,800	"	90,600	+18,600	-39,300
May	15,900	16,600	109.59	+.49	"	"	"	23,100	34,400	76,300	+ 4,300	-35,000
June	23,300	38,800	110.94	+1.35	25,300	25,000	"	33,500	13,500	72,000	-	"
July	23,600	20,100	111.61	+.67	"	"	"	50,400	-	75,400	+ 3,400	-31,600
Aug.	17,400	10,100	111.69	-.08	"	"	"	32,300	11,300	68,600	- 3,400	-35,000
Sept	14,400	7,000	111.55	-.14	"	"	"	17,400	29,600	72,000	-	"
Oct.	14,300	7,500	111.42	-.13	"	"	"	16,800	30,200	"	-	"
Nov.	13,700	8,400	111.30	-.12	"	"	"	10,800	36,200	"	-	"
Dec.	12,800	8,100	111.14	-.16	"	"	"	9,300	37,700	"	-	"
1960-Jan.	11,500	5,200	110.83	-.31	"	"	"	7,300	38,000	70,300	- 1,700	-36,700
Feb.	"	1,800	110.39	-.44	"	"	"	6,300	"	69,300	- 2,700	-39,400
Mar.	10,800	3,900	110.00	-.39	"	"	"	6,100	"	69,100	- 2,900	-42,300
Apr.	10,900	5,400	109.67	-.33	"	"	"	36,700	18,600	79,300	+ 7,300	-35,000
May	16,200	34,400	110.59	+.92	"	"	"	34,400	12,600	72,000	-	"
June	30,400	41,500	112.29	+1.70	"	"	"	36,000	11,000	"	-	"
July	27,300	26,900	113.00	+.71	34,800	"	9,800	37,400	9,600	"	-	"
Aug.	20,900	6,200	"	-	27,100	"	2,100	27,700	19,300	"	-	"
Sept.	16,200	10,000	"	-	26,200	"	1,200	13,800	33,200	"	-	"
Oct.	17,800	8,300	"	-	26,100	"	1,100	9,600	37,400	"	-	"
Nov.	16,600	5,700	112.89	-.11	25,300	"	300	6,600	38,000	69,600	- 2,400	-37,400
Dec.	15,200	7,800	112.81	-.08	"	"	"	5,200	"	68,200	- 3,800	-41,200

Year Month	Churchill R. @ Trade L.	Inflow Reindeer L.	Reindeer L. Elevation	Δ Storage Reindeer L.	Outflow Reindeer L.	Diverted Flow	Spillage to Island Fall	Saskatchewan River Flow	Pumping fro L. Winnipeg	Inflow Cedar L. - L. Winnipeg	Storage C.L. - L.W.	Cumulative Δ Storage
1961-Jan.	13,300	10,300	112.75	-.06	25,300	25,000	300	4,800	38,000	67,800	- 4,200	-45,400
Feb.	12,500	5,700	112.49	-.26	"	"	"	4,500	"	67,500	- 4,500	-49,900
Mar.	12,800	6,300	112.26	-.23	"	"	"	4,900	"	67,900	- 4,100	-54,000
Apr.	13,100	8,800	112.14	-.12	"	"	"	18,600	"	81,600	+ 9,600	-44,400
May	20,600	31,100	113.00	+.86	28,200	"	3,200	22,400	34,000	81,400	+ 9,400	-35,000
June	24,400	23,500	"	-	47,900	"	22,900	39,500	7,500	72,000	-	"
July	18,000	900	112.77	-.23	25,300	"	300	28,200	18,800	"	-	"
Aug.	14,700	800	112.41	-.36	"	"	"	21,600	25,400	"	-	"
Sept	11,800	26,700	112.89	+.48	"	"	"	13,000	34,000	"	-	"
Oct.	11,500	9,500	112.73	-.16	"	"	"	8,100	38,000	71,100	- 900	-35,900
Nov.	10,000	7,500	112.44	-.29	"	"	"	5,500	"	68,500	- 3,500	-39,400
Dec.	8,300	11,000	112.22	-.22	"	"	"	3,100	"	66,100	- 5,900	-45,300
1962-Jan.	7,400	6,400	111.80	-.42	"	"	"	4,400	"	67,400	- 4,600	-49,900
Feb.	7,000	5,100	111.32	-.48	"	"	"	5,400	"	68,400	- 3,600	-53,500
Mar.	6,700	6,700	110.88	-.44	"	"	"	6,300	"	69,300	- 2,700	-56,200
Apr.	7,000	3,900	110.35	-.53	"	"	"	14,000	"	77,000	+ 5,000	-51,200
May	20,900	24,100	111.07	+.72	"	"	"	39,800	23,400	88,200	+16,200	-35,000
June	22,400	13,400	111.45	+.38	"	"	"	30,000	17,000	72,000	-	"
July	18,200	20,700	111.95	+.50	"	"	"	31,700	15,300	"	-	"
Aug.	14,300	800	111.58	-.37	"	"	"	26,600	20,400	"	-	"
Sept	13,100	3,700	111.27	-.31	"	"	"	14,900	32,100	"	-	"
Oct.	12,200	7,200	111.05	-.22	"	"	"	4,400	38,000	67,400	- 4,600	-39,600
Nov.	10,900	9,000	110.85	-.20	"	"	"	3,700	"	66,700	- 5,300	-44,900
Dec.	9,800	4,300	110.44	-.41	"	"	"	3,900	"	66,900	- 5,100	-50,000
1963-Jan.	9,000	3,500	109.97	-.47	"	"	"	2,800	"	65,800	- 6,200	-56,200
Feb.	9,300	4,100	109.53	-.44	"	"	"	"	"	"	- 6,200	-62,400
Mar.	8,800	4,200	109.08	-.45	19,100	18,800	"	3,100	"	59,900	-12,100	-74,500
Apr.	9,600	29,100	109.80	+.72	"	"	"	23,000	"	79,800	+ 7,800	-66,700
May	15,700	26,300	110.41	+.61	25,300	25,000	"	28,900	"	91,900	+19,900	-46,800
June	15,400	29,400	111.12	+.71	"	"	"	27,400	31,400	83,800	+11,800	-35,000
July	28,300	8,500	111.43	+.42	"	"	"	39,100	7,900	72,000	-	"
Aug.	17,400	16,400	111.85	+.31	"	"	"	33,300	14,700	"	-	"
Sept	18,300	18,200	112.26	+.41	"	"	"	20,800	27,200	"	-	"
AVERAGE						21,820	1,390	21,350	28,960			

APPENDIX II

PHOTOGRAPHS

TAKEN DURING THE

RECONNAISSANCE FLIGHT OF THE

STURGEON-WEIR RIVER

SEPTEMBER, 1966.

This photograph shows the outlet of the Sturgeon-Weir River flowing into Cumberland Lake. The channel does not appear to be deep and is cut in overburden with low relief on both banks. Photo taken looking North.

This photograph taken looking East shows the Sturgeon-Weir River flowing into Namew Lake and the settlement at Sturgeon Landing. The very shallow nature of the channel can easily be seen from the photograph.

This photograph was taken looking East and shows the confluence of the Goose River and Sturgeon-Weir River to the right in the upper middle portion of the photograph. The Sturgeon-Weir Channel with some small islands in view flows from the lower left to upper right. The channel appears narrow and less than 10 feet deep.



This photograph shows the Sturgeon-Weir River at the inlet to Amisk Lake. The picture was taken looking northwest. Channel appears to be less than 10 feet deep.

Spruce Rapids on the Sturgeon-Weir River is seen in this photograph. The water appears very fast and the drop in two sections totals about 10 feet. A very definite rock control with much rock visible in the rapids section of the channel. This is discussed as a potential power site.

This photograph shows Scoop Rapids, another very narrow constriction in the Sturgeon-Weir River. Total drop is about 6 feet.

This photograph shows Birch Rapids on the Sturgeon-Weir River, a potential power site. A fairly concentrated drop of about 10 feet occurs at this site. The constricted portion appears to be formed by a gravel bar.

This photograph shows Three Portages, a series of three narrow rock-controlled constrictions in the upper Sturgeon-Weir River system. The discharge is presentl very small through the three constrictions and the total drop in water level is approximately 24 feet.

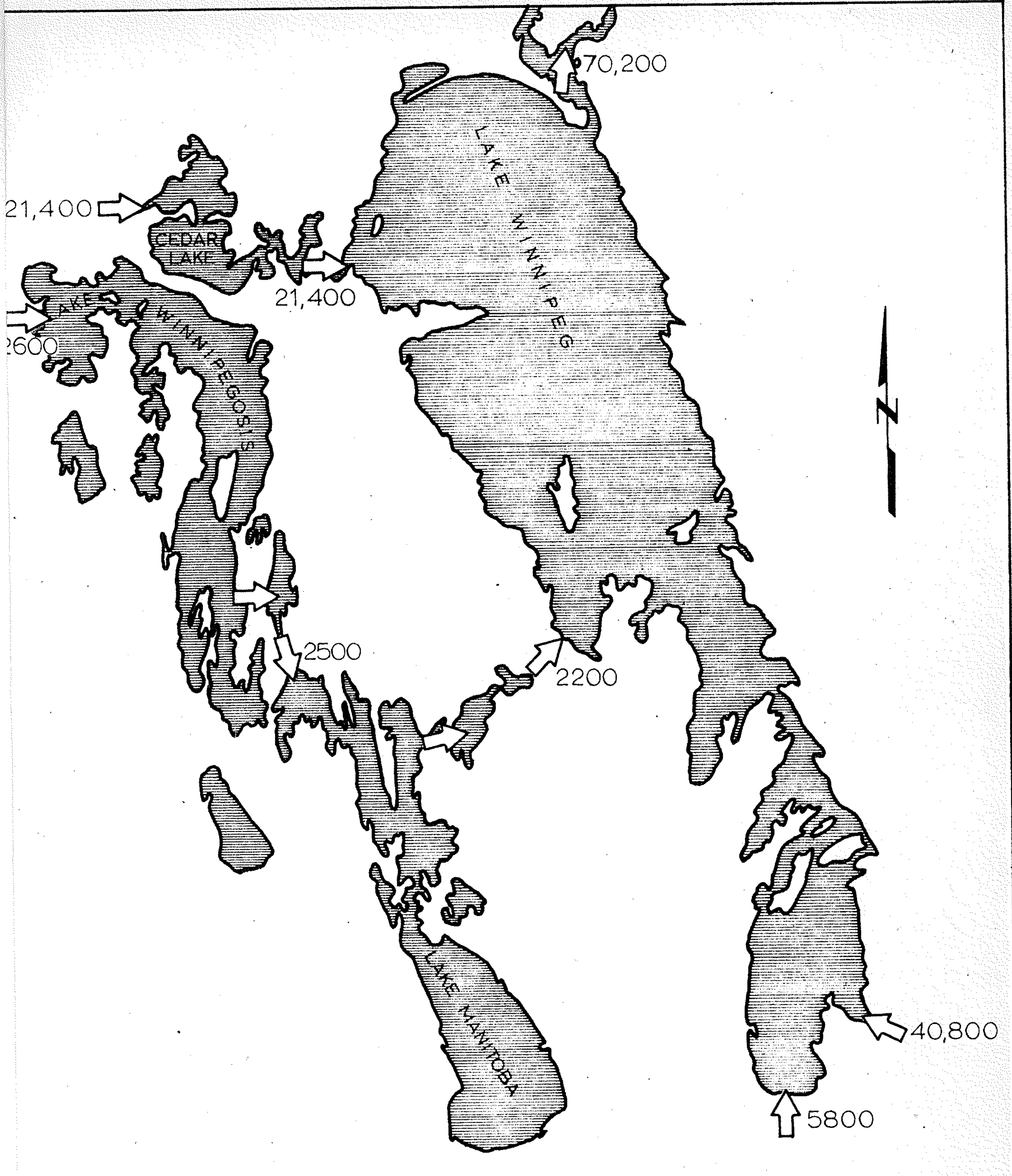
This photograph shows Grassy Narrows on Wood Lake, which is typical of the lakes in the upper Sturgeon-Weir. Dense spruce with some marshy areas is typical.

This photograph shows the height of land known as Frog Portage between Trade Lake on the Churchill River and the headwaters of the Sturgeon-Weir River channel. The well-worn portage trail which has been in use for hundreds of years is clearly in evidence in the upper part of the photograph. The natural overflow channel of the Churchill River is evidenced by a dark strip of vegetation which joins Trade Lake to the small pool in the photograph and then joins the pool to the stream at the upper right.

This photograph shows the narrow control section of the Churchill River, immediately downstream of the confluence with the Reindeer, in which it is proposed to construct the Downstream Control Structure. The photograph was taken looking east with the Reindeer River flowing into the Churchill from the left of the picture. The narrowest part of the Churchill is the proposed structure centreline.

This photograph was taken directly over the structure site described above. The photo was taken over the south bank of the Churchill, looking north. The swiftness of the water is apparent with a few rocks visible in the channel. Rock outcrop can be seen on both abutments.

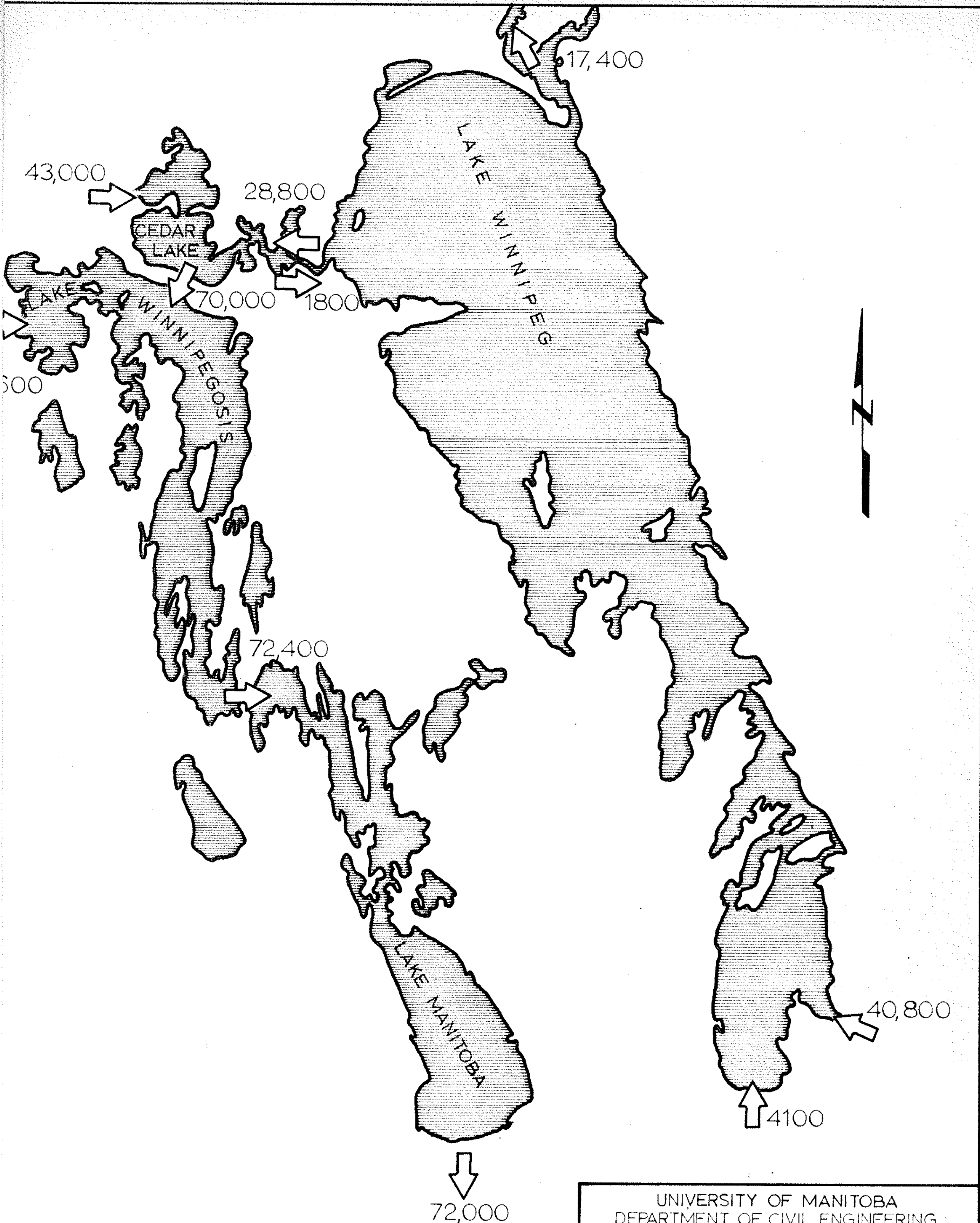
SEAL RIVER BASIN
HUDSON BAY
JAMES BAY
CHURCHILL
SEAL R.
SHETHANEI L.
TADOULE L.
CHIPEWYAN L.
SOUTHERN INDIAN L.
CHURCHILL R.
LAKE ATHABASCA
FOND-DU-LAC R.
WOLLASTON LAKE
SASKATCHEWAN
REINDEER LAKE
GRANVILLE LAKE
REINDEER RIVER
NELSON RIVER
KETTLE RAPIDS
THOMPSON
BURNTWOOD R.
RAT R.
ALBERTA
CHURCHILL LAKE
CHURCHILL RIVER BASIN
MANITOBA
LAC LA RONGE
BEAVER RIVER
FLIN FLON
CROSS LAKE
SEE PLATE 3-1
MOOSE LAKE
THE PAS
CEDAR LAKE
GRAND RAPIDS
SEE PLATE 4-1
JASPER
EDMONTON
NORTH SASKATCHEWAN R.
PRINCE ALBERT
BRITISH COLUMBIA
RED DEER
SASKATCHEWAN RIVER BASIN
SASKATOON
BANFF
DRUMHELLER
CALGARY
BOW RIVER
SOUTH SASKATCHEWAN RIVER
ASSINIBOINE RIVER
YORKTON
LAKE WINNIPEG
LAKE DAUPHIN
LAKE MANITOBA
WINNIPEG R.
WINNIPEG R. BASIN
ONTARIO
LAKE ST JOSEPH
LAC SEUL
LAKE NIPIGON
MEDICINE HAT
SWIFT CURRENT
REGINA
QU'APPELLE RIVER
LETHBRIDGE
BRANDON
ASSINIBOINE RIVER
WINNIPEG
LAKE OF THE WOODS
RAINY LAKE
RAINY RIVER
RED RIVER
NELSON RIVER BASIN INCLUDES SASKATCHEWAN
SOURIS RIVER
UPPER RED LAKE
LOWER RED LAKE
LAKE SUPERIOR
0 50 100 150 200 250 300
SCALE IN MILES
NORTH DAKOTA
MINNESOTA
SOUTH DAKOTA
60°
55°
50°
45°
115°
110°
105°
100°
95°
UNIVERSITY OF MANITOBA
DEPARTMENT OF CIVIL ENGINEERING
WATER RESOURCES INVESTIGATION
LOCATION PLAN OF DRAINAGE BASINS
DATE
APRIL 1967
MASTER OF SCIENCE THESIS
G.A. FILMON
PLATE NO.
1-1
RCL



NOTE :
VALUES SHOWN ARE MEAN ANNUAL DISCHARGE IN C.F.S.
ARROWS REPRESENT COMBINED DISCHARGE FROM SEVERAL RIVERS, IN SOME CASES.

RCL.

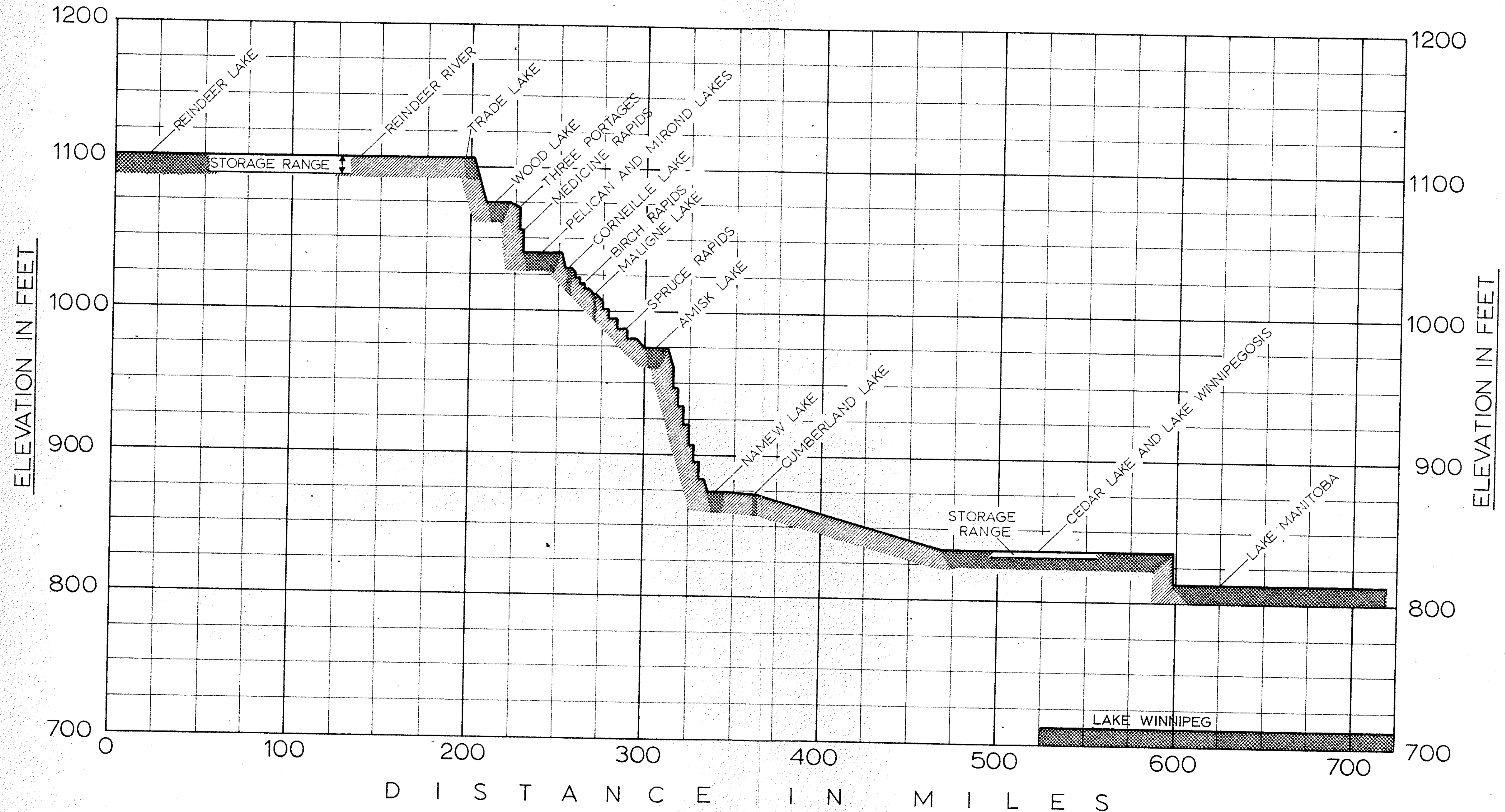
UNIVERSITY OF MANITOBA DEPARTMENT OF CIVIL ENGINEERING		
WATER RESOURCES INVESTIGATION		
CASE 1 PRESENT LONG TERM AVERAGE. INFLOWS AND OUTFLOWS		
DATE APRIL 1967	MASTER OF SCIENCE THESIS G.A. FILMON	PLATE NO. 1-2



NOTE :
VALUES SHOWN ARE MEAN ANNUAL DISCHARGE IN C.F.S.
ARROWS REPRESENT COMBINED DISCHARGE FROM SEVERAL RIVERS, IN SOME CASES.

RCL

UNIVERSITY OF MANITOBA DEPARTMENT OF CIVIL ENGINEERING		
WATER RESOURCES INVESTIGATION		
CASE II PROPOSED INFLOWS AND OUTFLOWS		
DATE	MASTER OF SCIENCE THESIS G.A. FILMON	PLATE NO.
APRIL 1967		1-3



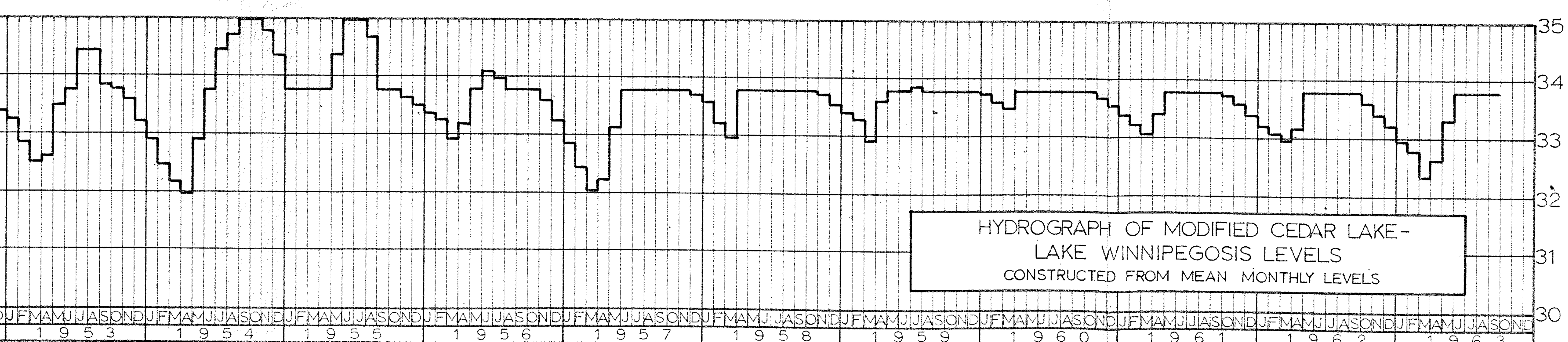
UNIVERSITY OF MANITOBA
DEPARTMENT OF CIVIL ENGINEERING

WATER RESOURCES INVESTIGATION

WATER SURFACE PROFILE
ALONG DIVERSION ROUTE

DATE	MASTER OF SCIENCE THESIS	PLATE NO.
APRIL 1967	G.A. FILMON	1-4

RCL.



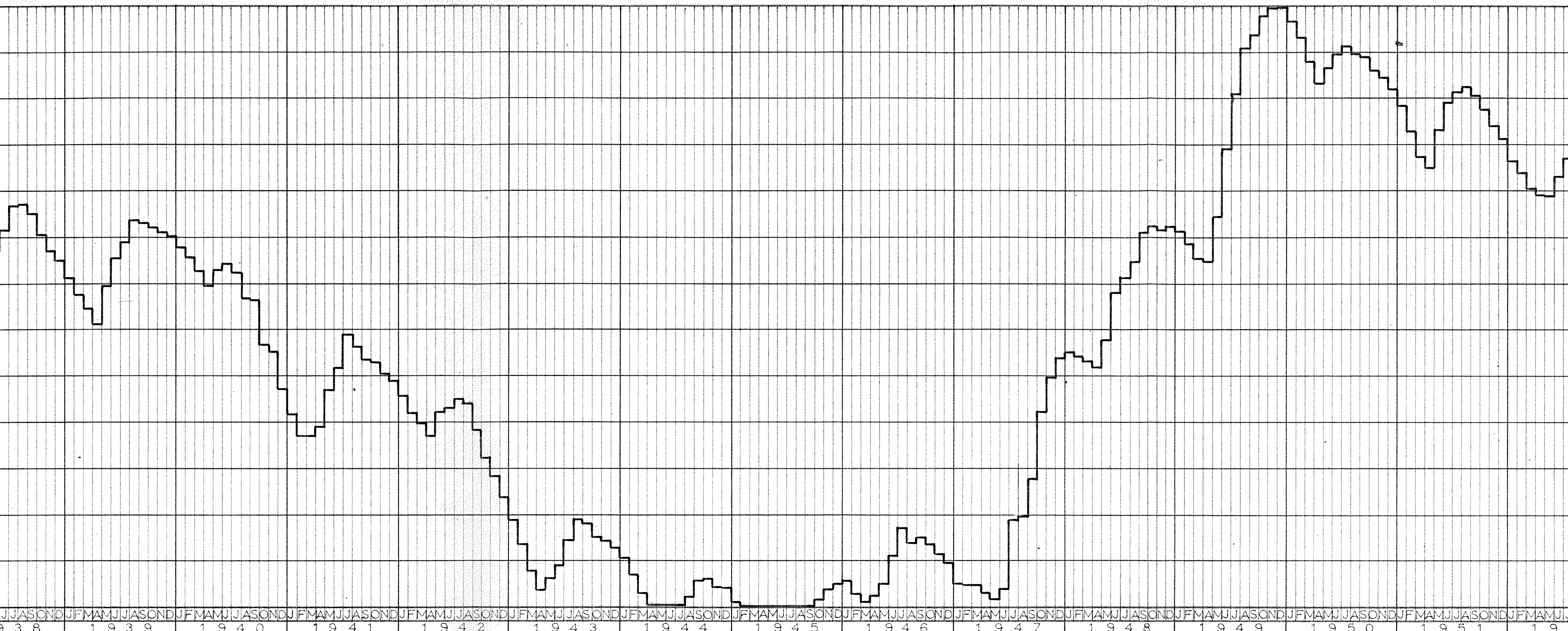
RCL.

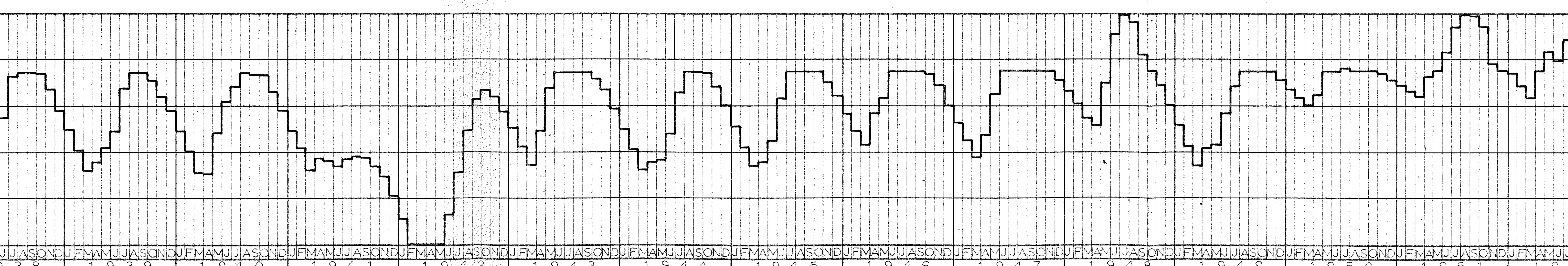
UNIVERSITY OF MANITOBA
DEPARTMENT OF CIVIL ENGINEERING

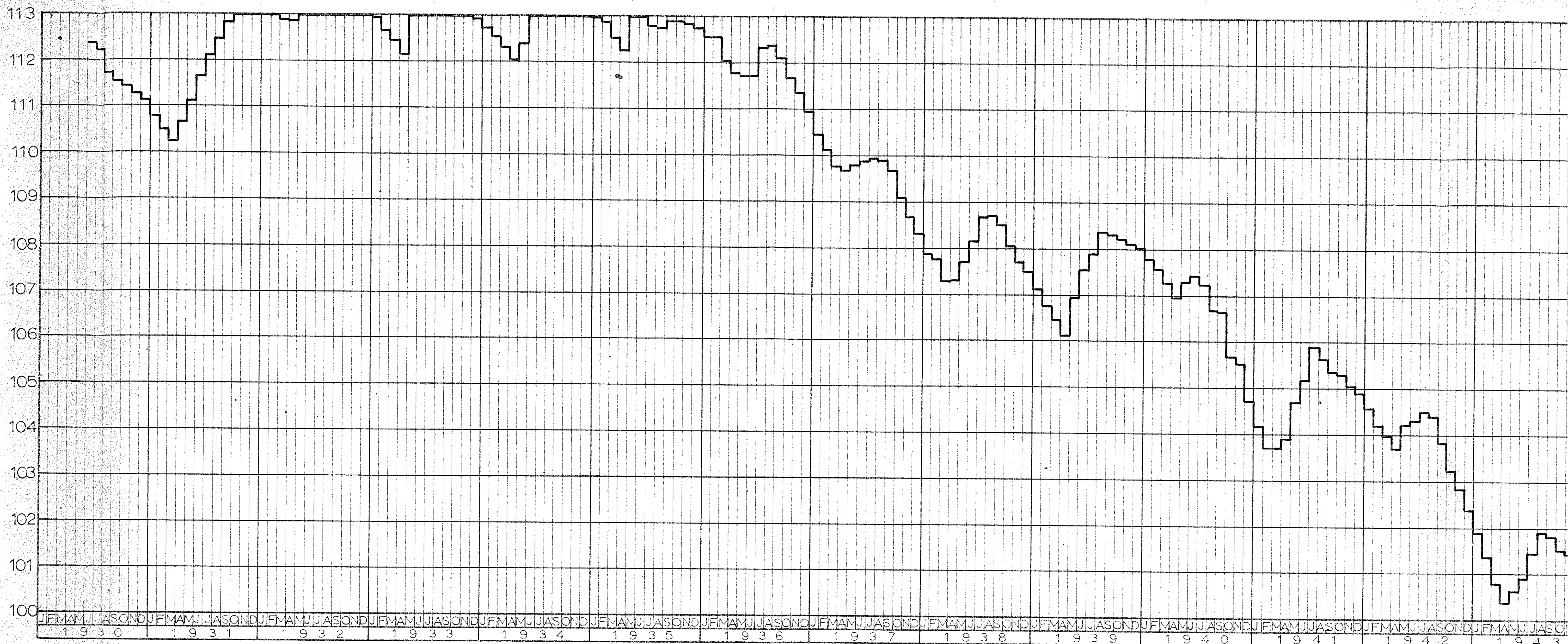
WATER RESOURCES INVESTIGATION

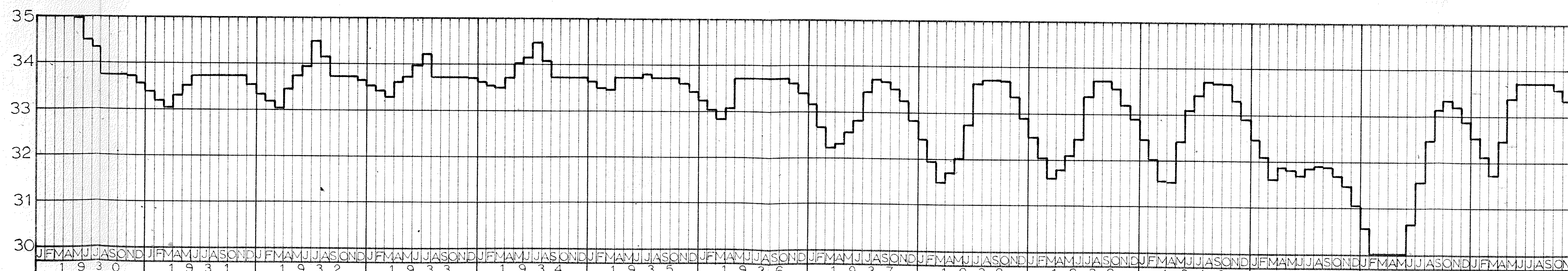
STORAGE HYDROGRAPHS

DATE		PLATE NO.
APRIL 1967	MASTER OF SCIENCE THESIS G.A. FILMON	2-1

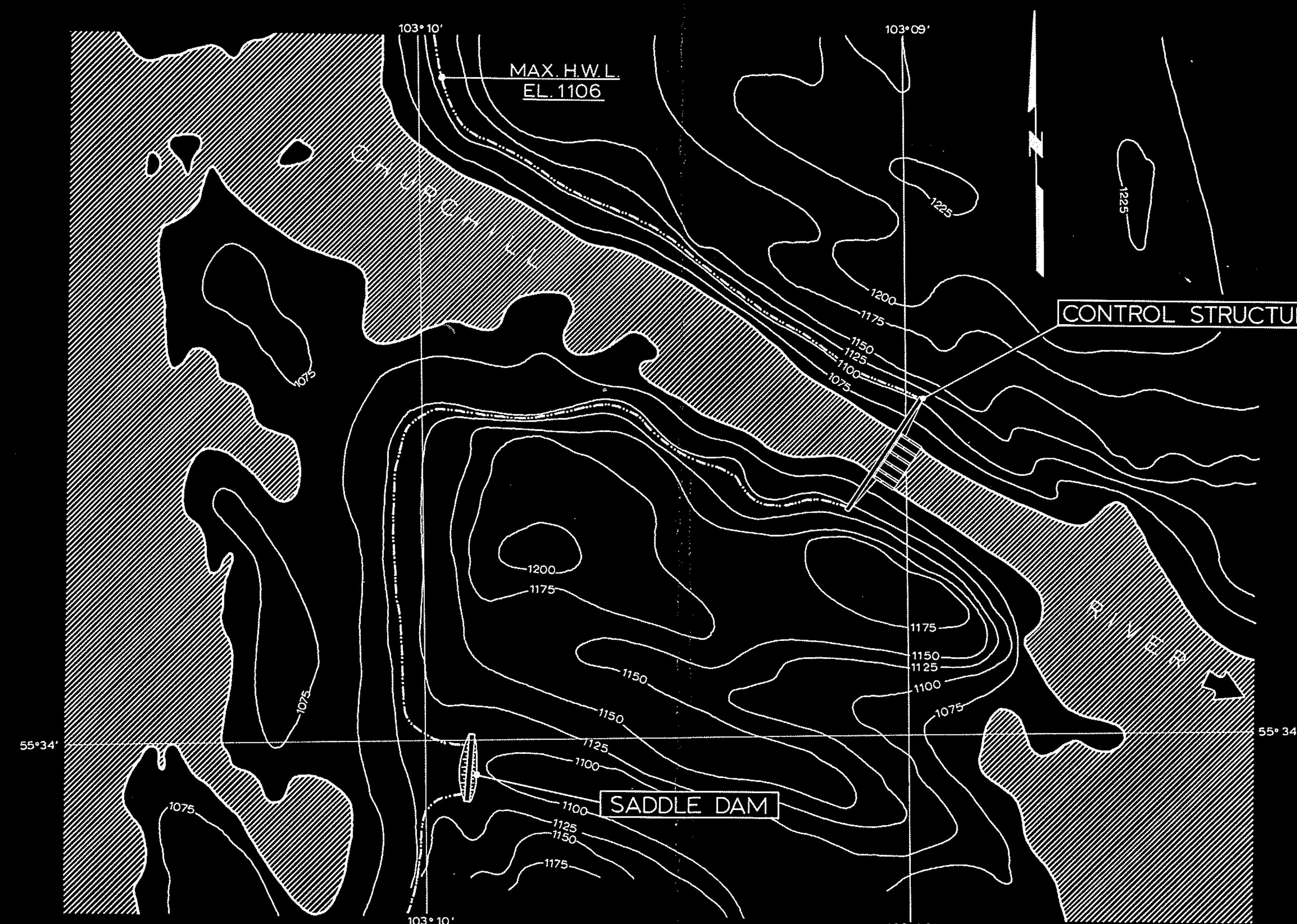

938
1939
1940
1941
1942
1943
1944
1945
1946
1947
1948
1949
1950
1951
195


938
1939
1940
1941
1942
1943
1944
1945
1946
1947
1948
1949
1950
1951
195


113
112
111
110
109
108
107
106
105
104
103
102
101
100
J F M A M J J A S O N D
1930
1931
1932
1933
1934
1935
1936
1937
1938
1939
1940
1941
1942
1943


35
34
33
32
31
30
J F M A M J J A S O N D
1930
1931
1932
1933
1934
1935
1936
1937
1938
1939
1940
1941
1942
1943

UNIVERSITY OF MANITOBA
DEPARTMENT OF CIVIL ENGINEERING
WATER RESOURCES INVESTIGATION
LOCATION PLAN OF CHURCHILL RIVER DIVERSION SHOWING FLOODED AREAS
DATE: APRIL 1967 | MASTER OF SCIENCE THESIS, G.A. FILMON | PLATE NO. 3-1

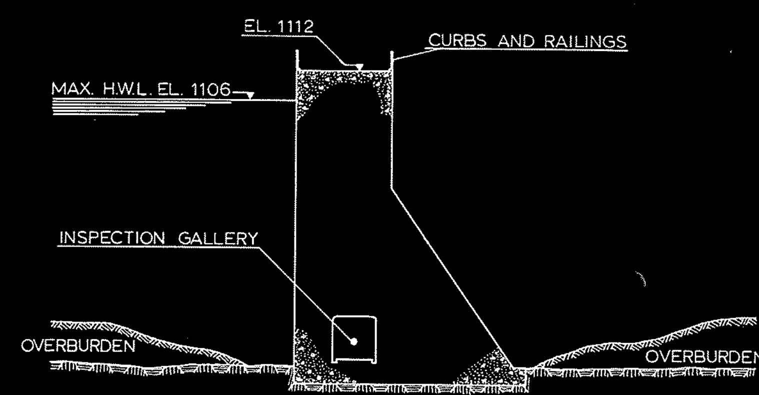


0 400 800 1200
200 600 1000
SCALE IN FEET

NOTE:
EXTENT OF FLOODED AREA
SHOWN THUS : —··—··—··—

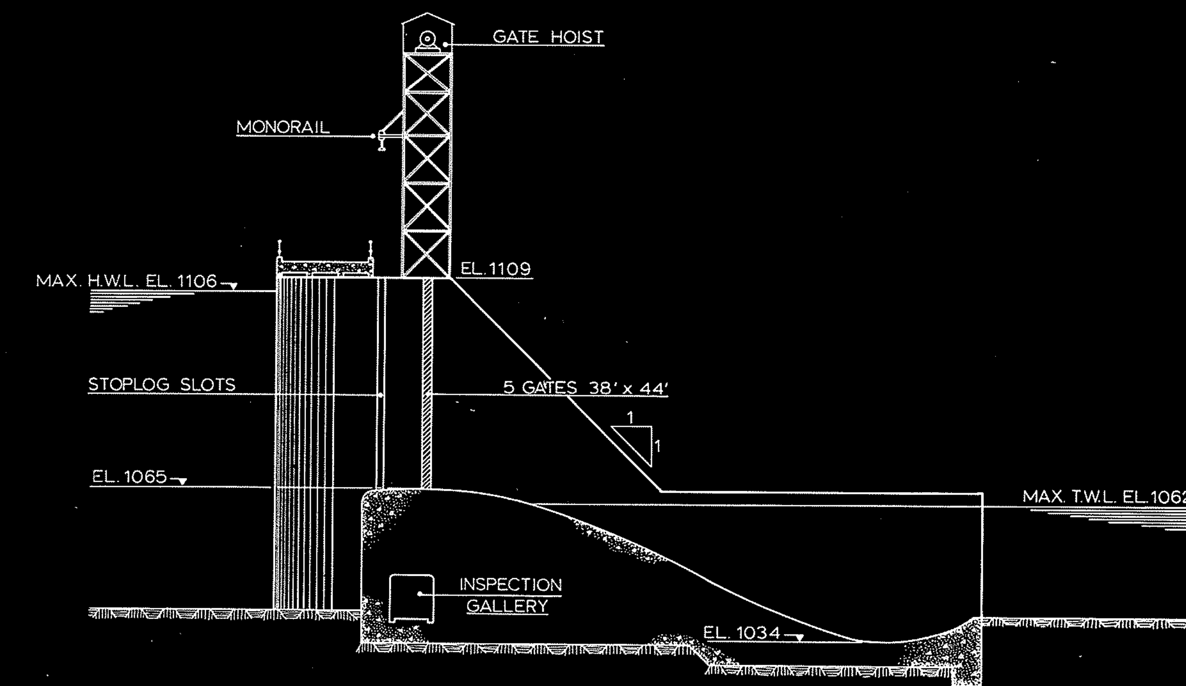
UNIVERSITY OF MANITOBA DEPARTMENT OF CIVIL ENGINEERING		
WATER RESOURCES INVESTIGATION		
CHURCHILL RIVER DIVERSION DOWNSTREAM CONTROL GENERAL ARRANGEMENT		
DATE APRIL 1967	MASTER OF SCIENCE THESIS G.A. FILMON	PLATE NO. 3-2

RCL



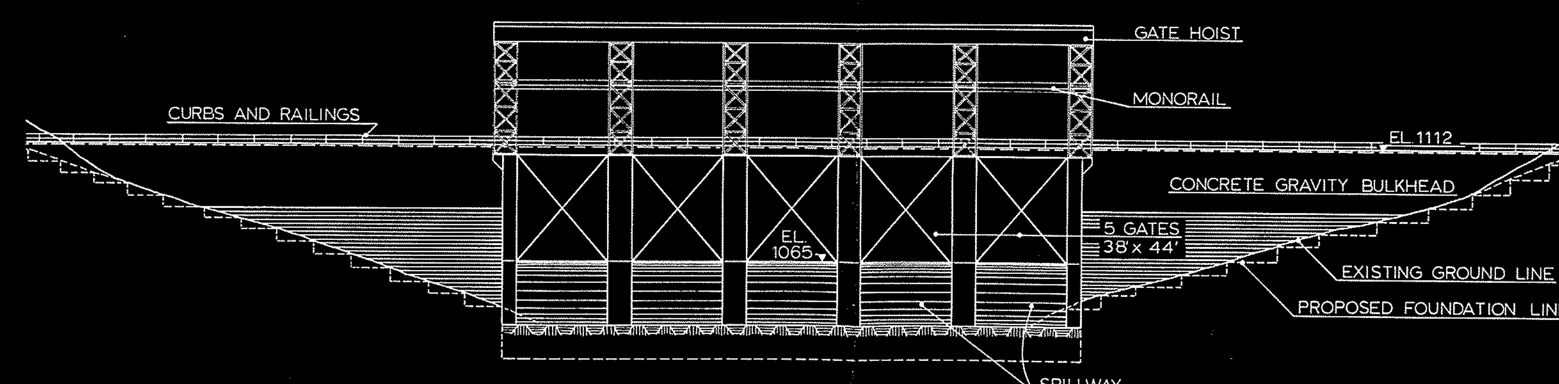
CONCRETE GRAVITY BULKHEAD
TYPICAL CROSS SECTION

SCALE IN FEET



SPILLWAY
CROSS SECTION

SCALE IN FEET



DOWNSTREAM ELEVATION

SCALE IN FEET

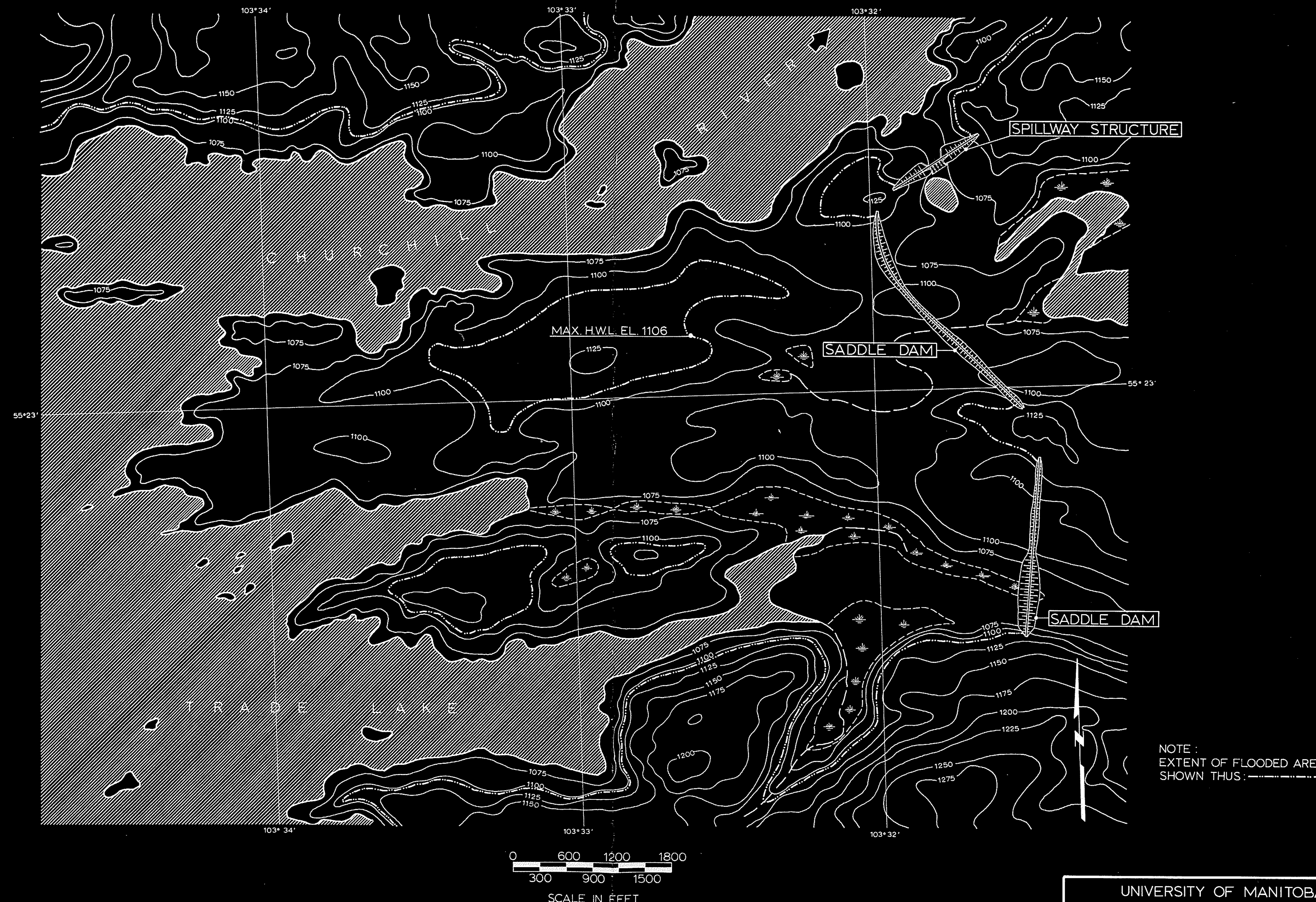
UNIVERSITY OF MANITOBA
DEPARTMENT OF CIVIL ENGINEERING

WATER RESOURCES INVESTIGATION

CHURCHILL RIVER DIVERSION
DOWNSTREAM CONTROL
SECTIONS AND DETAILS

DATE		PLATE NO.
APRIL 1967	MASTER OF SCIENCE THESIS G.A. FILMON	3-3

RCL



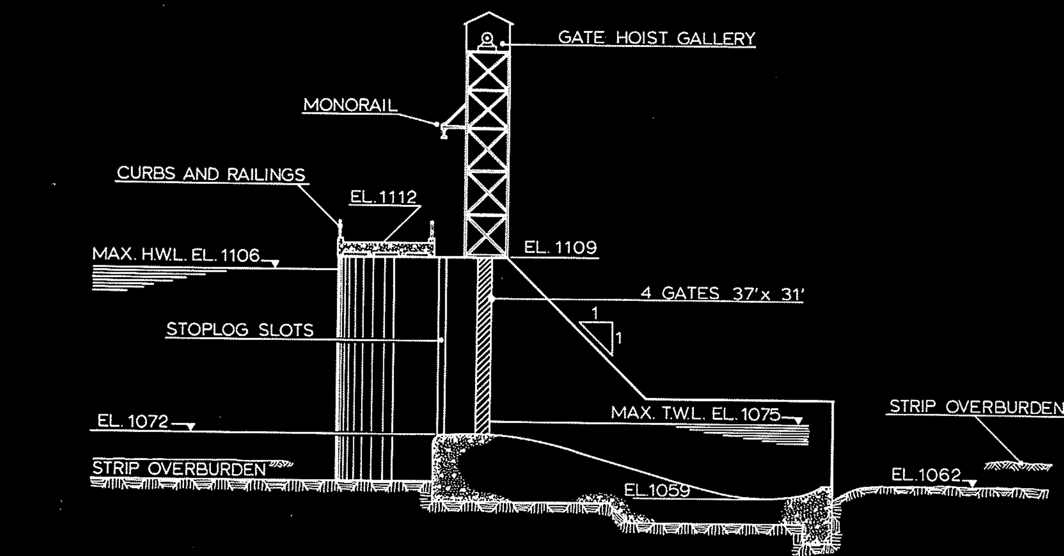
UNIVERSITY OF MANITOBA
DEPARTMENT OF CIVIL ENGINEERING

WATER RESOURCES INVESTIGATION

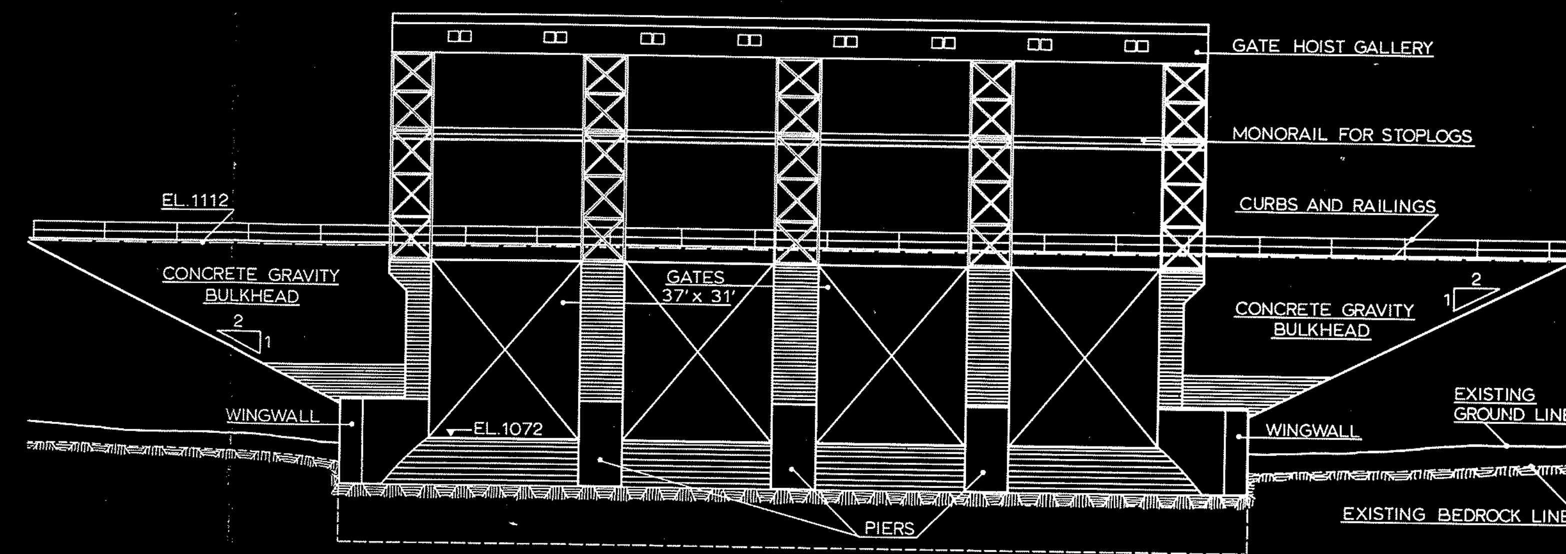
CHURCHILL RIVER DIVERSION
FROG PORTAGE CONTROL
GENERAL ARRANGEMENT

DATE		PLATE NO.
APRIL 1967	MASTER OF SCIENCE THESIS G.A. FILMON	3-4

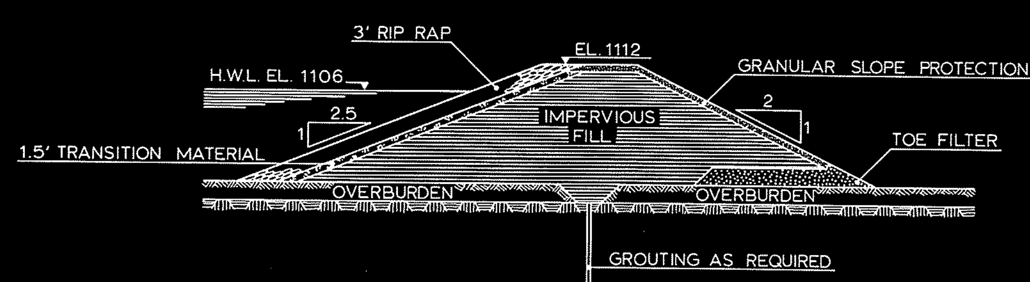
RCL



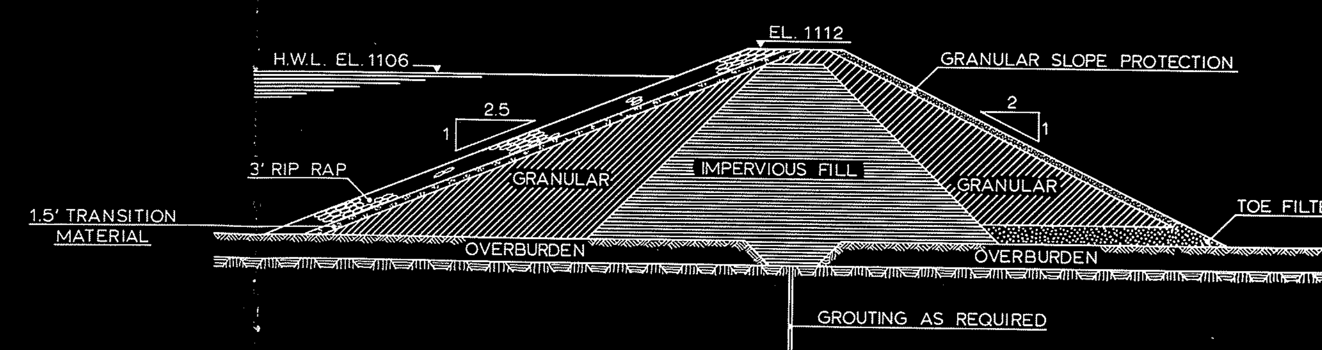
FROG PORTAGE SPILLWAY
CROSS SECTION



SPILLWAY DOWNSTREAM ELEVATION



HOMOGENEOUS EARTHFILL SECTION
< 25' IN HEIGHT

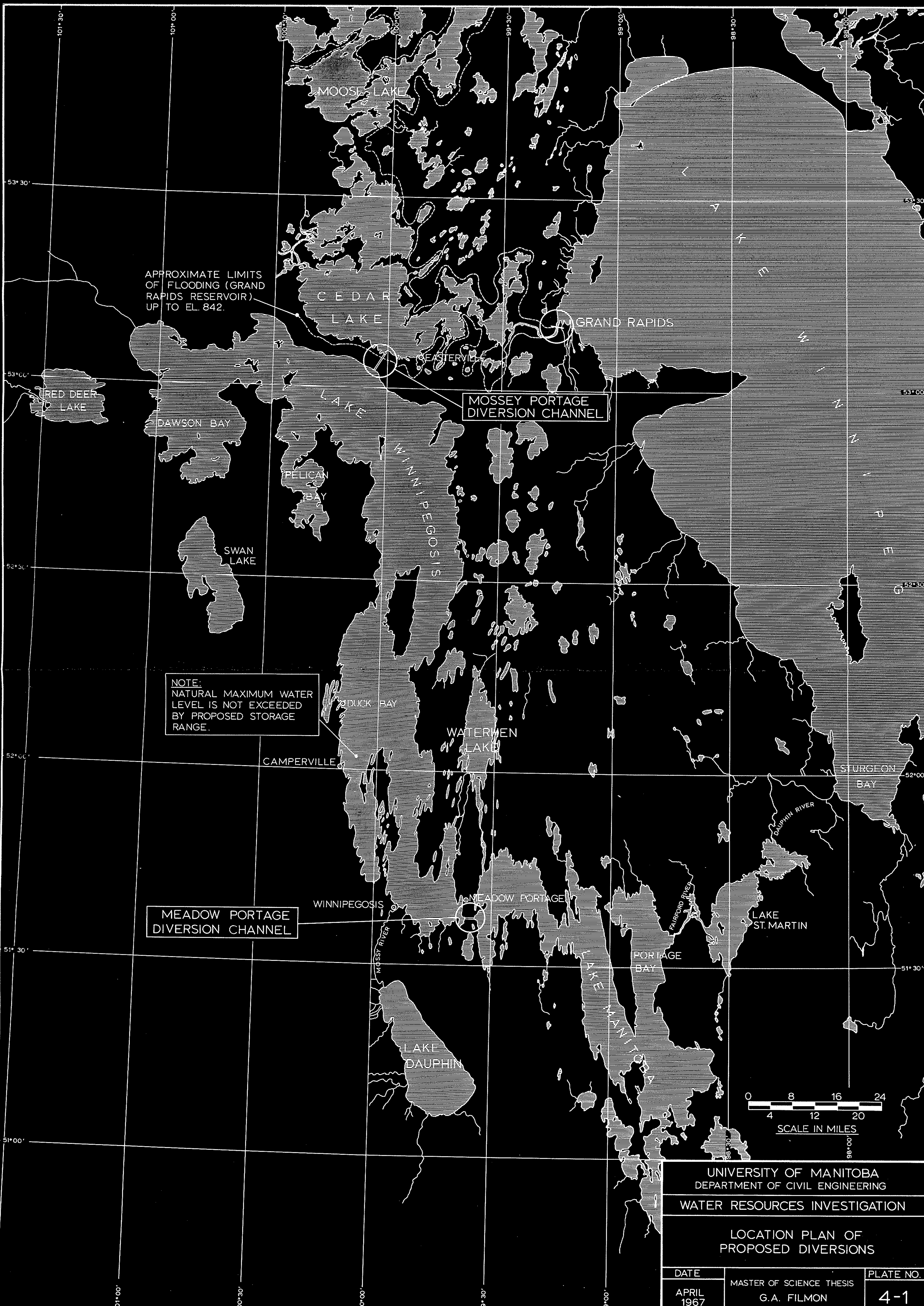


ZONED EARTHFILL SECTION
> 25' IN HEIGHT

SCALE IN FEET

UNIVERSITY OF MANITOBA DEPARTMENT OF CIVIL ENGINEERING		
WATER RESOURCES INVESTIGATION		
CHURCHILL RIVER DIVERSION FROG PORTAGE CONTROL SECTIONS AND DETAILS		
DATE APRIL 1967	MASTER OF SCIENCE THESIS G. A. FILMON	PLATE NO. 3-5

RCL

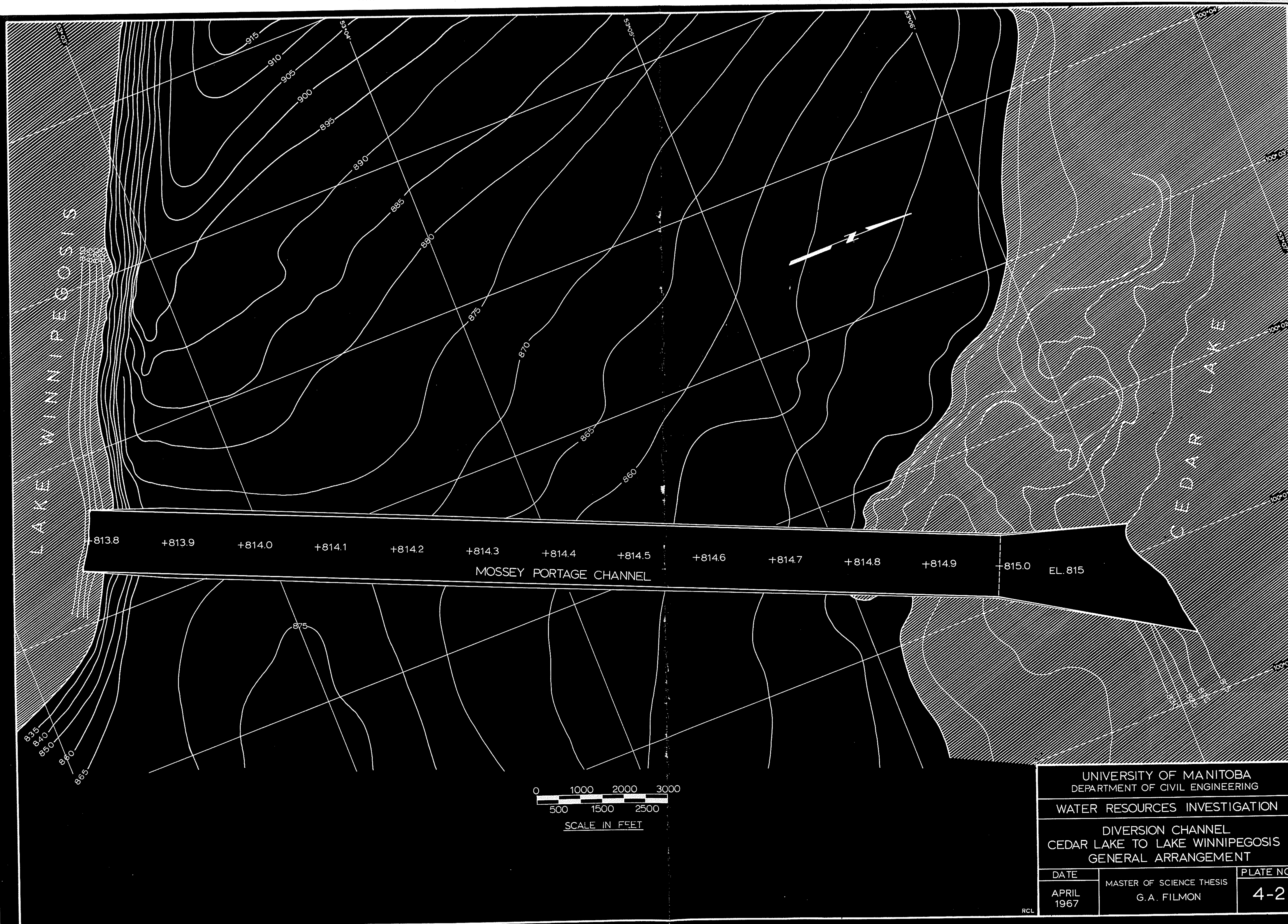


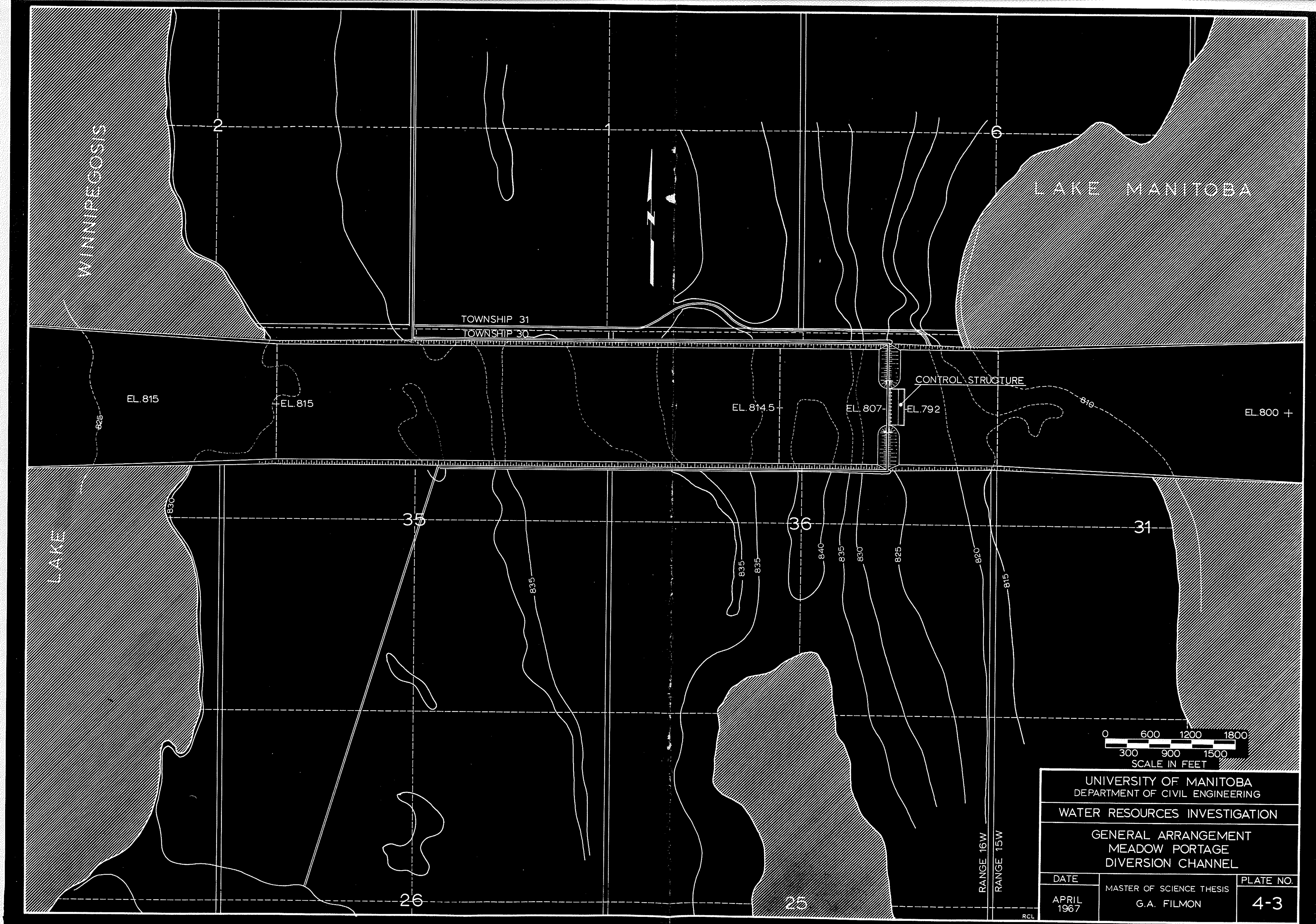
UNIVERSITY OF MANITOBA
DEPARTMENT OF CIVIL ENGINEERING

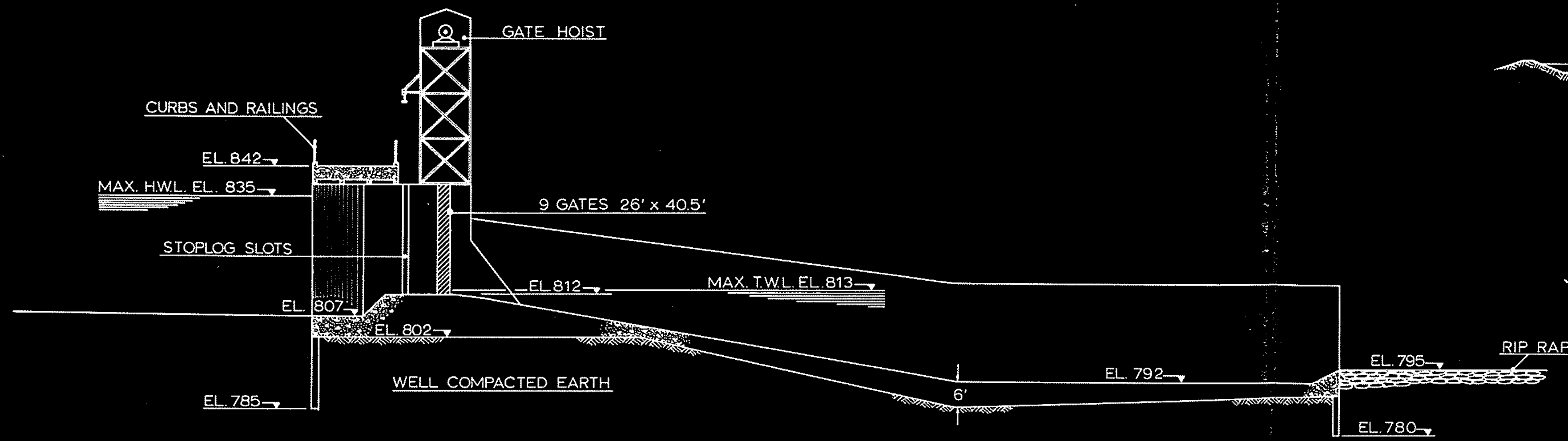
WATER RESOURCES INVESTIGATION

LOCATION PLAN OF PROPOSED DIVERSIONS

DATE		PLATE NO.
APRIL 1967	MASTER OF SCIENCE THESIS G.A. FILMON	4-1


LAKE WINNIPEGOSIS
CEDAR LAKE
MOSSEY PORTAGE CHANNEL
+813.8
+813.9
+814.0
+814.1
+814.2
+814.3
+814.4
+814.5
+814.6
+814.7
+814.8
+814.9
+815.0
EL. 815
915
910
905
900
895
890
885
880
875
870
865
860
835
840
850
N
0
1000
2000
3000
500
1500
2500
SCALE IN FEET
UNIVERSITY OF MANITOBA
DEPARTMENT OF CIVIL ENGINEERING
WATER RESOURCES INVESTIGATION
DIVERSION CHANNEL
CEDAR LAKE TO LAKE WINNIPEGOSIS
GENERAL ARRANGEMENT
DATE
APRIL 1967
MASTER OF SCIENCE THESIS
G.A. FILMON
PLATE NO.
4-2
RCL


LAKE WINNIPEGOSIS
LAKE MANITOBA
TOWNSHIP 31
TOWNSHIP 30
CONTROL STRUCTURE
EL. 815
EL. 815
EL. 814.5
EL. 807
EL. 792
EL. 800
2
1
6
35
36
31
26
25
RANGE 16W
RANGE 15W
0 600 1200 1800
300 900 1500
SCALE IN FEET
UNIVERSITY OF MANITOBA
DEPARTMENT OF CIVIL ENGINEERING
WATER RESOURCES INVESTIGATION
GENERAL ARRANGEMENT
MEADOW PORTAGE
DIVERSION CHANNEL
DATE
APRIL 1967
MASTER OF SCIENCE THESIS
G.A. FILMON
PLATE NO.
4-3

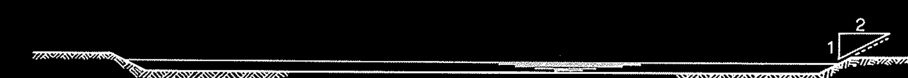


CROSS SECTION THROUGH SPILLWAY
MEADOW PORTAGE

0 20 40 60
10 30 50
SCALE IN FEET

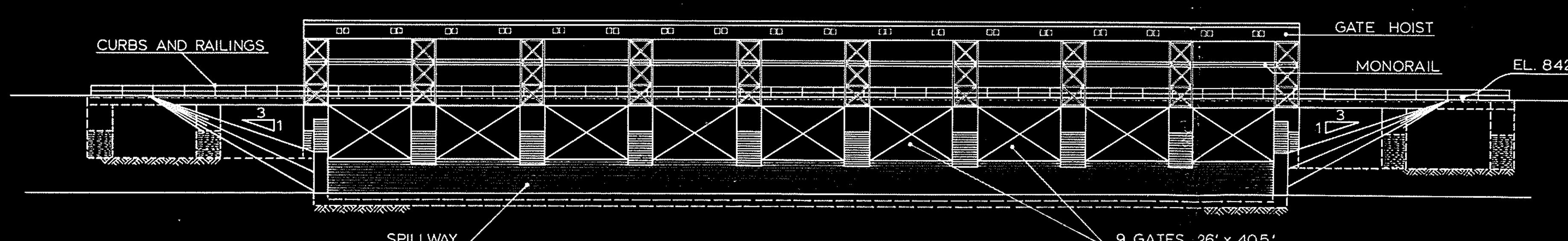
SECTION THROUGH MEADOW PORTAGE CHANNEL

0 200 400 600
100 300 500
SCALE IN FEET



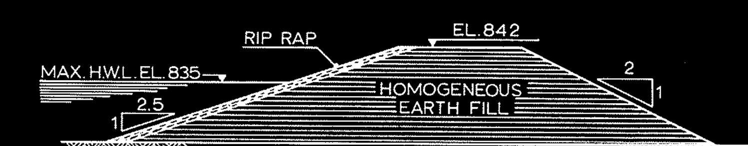
SECTION THROUGH MOSSEY PORTAGE CHANNEL

0 200 400 600
100 300 500
SCALE IN FEET



SPILLWAY DOWNSTREAM ELEVATION
MEADOW PORTAGE

0 40 80 120
20 60 100
SCALE IN FEET



EARTH FILL SECTION
MEADOW PORTAGE

0 20 40 60
10 30 50
SCALE IN FEET

UNIVERSITY OF MANITOBA
DEPARTMENT OF CIVIL ENGINEERING

WATER RESOURCES INVESTIGATION

MEADOW PORTAGE AND
MOSSEY PORTAGE CHANNELS
SECTIONS AND DETAILS

DATE		PLATE NO.
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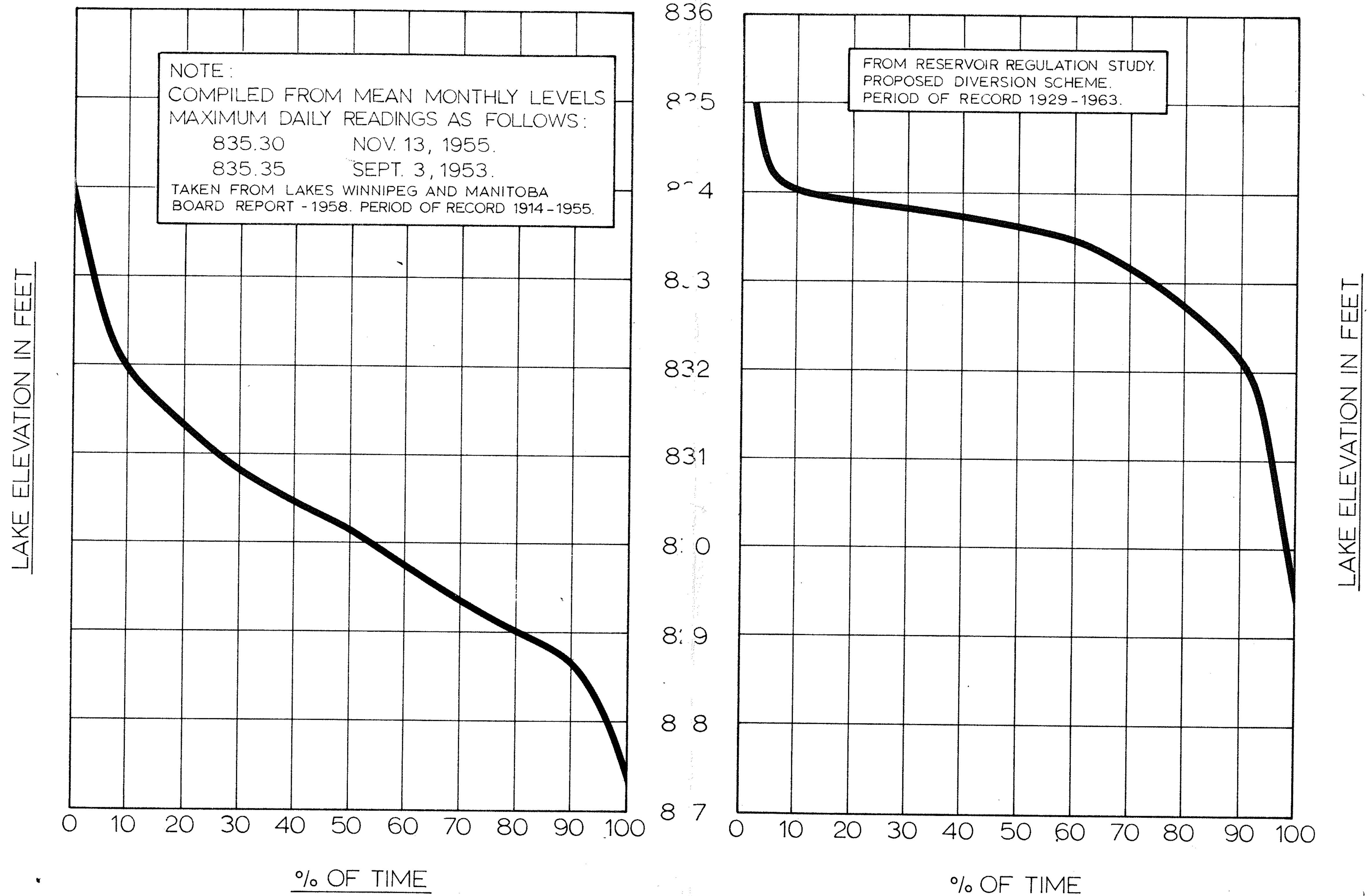
R.C.L.



UNIVERSITY OF MANITOBA
DEPARTMENT OF CIVIL ENGINEERING

WATER RESOURCES INVESTIGATION

STAGE-DURATION CURVES
LAKE WINNIPEGOSIS

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